PRINCIPLES

OF

AGRICULTURAL CHEMISTRY,

WITH

SPECIAL REFERENCE

TO THE

LATE RESEARCHES MADE IN ENGLAND.

BY

JUSTUS VON LIEBIG.

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TO

MY FRIEND

DR. CHARLES DAUBENY,

PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF OXFORD,

THE ZEALOUS PROPAGATOR

OF

SCIENTIFIC PRINCIPLES IN AGRICULTURE,

This little Work

IS DEDICATED BY

THE AUTHOR.

MUNICH,
March 4th, 1855.

EDITOR'S ADVERTISEMENT.

I CANNOT allow this little treatise to appear without expressing the very high gratification I have had in translating it, and thus assisting to lay it before the British public.

It is, so far as I can judge, by far the best of the author's writings on the important subject to which it refers.

Apart from all controversy, it contains, in the shape of fifty propositions, a most admirable summary of the true relation between Chemistry and Agriculture. These propositions are beyond all doubt true, so far as our present knowledge extends, and contain principles, the due appreciation and application of which is of the last importance to all who wish to cultivate Agriculture on true, that is, on scientific principles.

No doubt can be entertained by any one who has read the various memoirs published by writers opposed to the author's views, that these views and the principles or doctrines he has hitherto laid down, have been generally misunderstood by these writers, and that failure and disappointment have been the natural results.

But in the fifty propositions now given to the world, the real doctrines of the author are so simply and clearly expressed, that it is almost impossible not to understand and appreciate them; and it may be confidently expected, that their promulgation will produce most beneficial results.

I trust that I may be allowed to express this hope, since these propositions embody, in a fuller and more extended form, those principles of Agricultural Chemistry, or rather of the science of Agriculture, which I have deduced from the author's writings, and which I have long taught in my lectures, frequently in the very words now used by their author. So strong is my conviction of the truth of these principles, that I regard it as certain,

that all real improvements in Agriculture will be found, on examination, to be referable to these principles or laws, and that, as Baron Liebig somewhere has said, "therein lies the whole future of Agriculture."

The present work demonstrates that the author's so-called "Mineral Theory" has been entirely misunderstood by Mr. Lawes, and that the experiments of the latter gentleman, in all points, really prove the truth of the "Theory," as it exists in the author's works.

It is most gratifying to observe that the controversy has been conducted, on both sides, with perfect temper and good feeling, and this circumstance will greatly enhance the value and efficacy of that portion of it now published.

WILLIAM GREGORY,
Professor of Chemistry in the University of Edinburgh.

EDINBURGH,
March 1*st*, 1855.

PRINCIPLES

OF

AGRICULTURAL CHEMISTRY.

My attention having been lately again directed to the applications of chemistry to agriculture and vegetable physiology, I found it necessary to go through the "Agricultural Journals" published since 1845, in order to acquire some knowledge of the experience recorded since that time. Of all the memoirs which have as yet appeared on this subject, that of Mr. J. B. Lawes, of Rothamsted, is the most remarkable, on account of the extent and duration of the experiments undertaken by him; and as the conclusion at which he has arrived, and the consequences which he has deduced from it, are in contradiction to the principles which I have laid down, I consider what he calls his practical criticism on scientific views as peculiarly adapted to

serve as an example, by which agriculturalists may be convinced how necessary it is to choose a correct method in the institution of experiments, if such experiments are designed either to convey instruction, or to confirm or to refute views already promulgated.

In fact, all the experiments of Mr. Lawes prove exactly the reverse of that which in his opinion they ought to demonstrate. Nay, I regard them as the most incontestable proofs in favour of that very doctrine, which they were originally intended to disprove; and the facts which he has established yield so many important lessons, in regard to the cultivation and manuring of the various soils, that I consider these facts of most especial value for the theory of agriculture.

But before subjecting these experiments to a searching inquiry, I think it will be advantageous to premise a few words on the true method of experimenting in general, and on its significance, as well as on the relation which exists between the chemist and the art of agriculture. This relation is very commonly inaccurately apprehended, and from such erroneous notions arise the most singular misunderstandings.

The investigation of natural phenomena, in the

course of its regular development, arrives at certain fundamental principles or laws, the truth of which, when once ascertained and demonstrated, requires no further proof. In considering this subject, we must distinguish those laws derived from reasoning from those derived from experience. All natural laws are obtained from experience, that is to say, they are truths, which have been established by observation and experience. That the air possesses weight; that is, is attracted by the earth; that a body which burns in the air combines with an ingredient of the air; that the weight of a chemical compound is equal to the sum of the weights of its component parts; these are laws of nature. The constant occurrence of phosphoric acid, of alkalies, and of lime in the blood, in the organs of animals, and in the seeds and juices of plants, is a law of nature. Again, that carbonic acid gas contains its own volume of oxygen; that one volume of oxygen combines with two of hydrogen: these also are natural laws. It is plain, that if these fundamental truths, or natural laws, are to be applied to the explanation of certain changes or processes in the arts, in agriculture, or in other sciences, our insight into these operations depends essentially on our knowledge of the processes themselves, and on

a right understanding of the natural laws which have a share in them.

When one of these two conditions is deficient or altogether wanting, conclusions are often arrived at, which are opposed to the laws of nature, or which seem to prove, that these laws are not sufficient to explain the phenomena. When we wish to apply these principles, or to bring the natural laws into operation, that is, as it is commonly expressed, to make an experiment, the success of that experiment depends essentially on the presence of all those conditions, on the simultaneous or successive action of which the phenomenon depends. And when the experiment does not give the same result as that which we had anticipated, this is always a sure sign, that one or other of the conditions has been inoperative, or has been wanting. The failure of the experiment can never be regarded as a proof, that those principles, which are only expressions of natural laws, that is, of facts, are not true, since their truth has already been established by the most indisputable evidence.

In like manner, the success of an experiment can never be regarded as proof of the truth of an opinion, when that opinion is in contradiction to established natural laws. Thus, the fact that a

man can raise himself from a plain into the air, to the height of many thousand feet, and with great velocity, cannot be considered as a proof that the force of gravity does not act on him; although the rise of a balloon is a phenomenon exactly opposed to that of the fall of bodies to the earth when left to themselves. When an experiment is intended to prove the truth of a view or opinion, we must, above all things, if it succeed, explain why it has succeeded; that is, the conditions of its success, and their cooperation in agreement with the laws of nature, must be sought for and determined.

An experiment, no matter whether it succeed or fail, is, considered by itself, merely a naked fact, which explains nothing, unless its success or failure be brought into connexion with the natural laws, by whose operation the result has been determined.

There is no phenomenon, no natural process, no experiment, which admits of explanation by only one natural law. Several such laws invariably cooperate to bring about the result. Thus, to explain the rise of a balloon, we must know four natural laws. The explanation of the rise and fall of the barometer, or that of the lowering of the boiling point of liquids on high mountains, presupposes an acquaintance with three natural laws.

The expression for the connexion of all the natural laws, by the cooperation of which a natural phenomenon or a natural process is produced or effected, is called the theory of the phenomenon or process.

The word theory, in natural science, has no other meaning; and hence it may be seen how very far the notion of a theory in this sense differs from that attached to the word theory in ordinary language. In the latter, it often means the exact contrary of experience, the want of knowledge of facts, and of natural laws. But in the true scientific sense, theory is the sum of all experience, of all observations and experiments, and it is founded on the most accurate knowledge both of facts and of natural laws, for the obvious reason that it is the result of this knowledge. The statement, that the fertility of a soil increases or diminishes in direct proportion to the supply of what is called the mineral food of plants is no true theory, because the produce of a field, in the number and bulk of the plants grown on it, depends also on two other indispensable conditions, which are not included in the "mineral food of plants:" a true theory is the expression of all the necessary conditions, and none of these can be omitted.

At the present day, in physics and chemistry, we have no longer theorists in the sense of the schools of the last century. Under this term were understood men, endowed with a lively imagination, who, without instituting farther inquiries into natural laws, allowed a natural phenomenon, as it were, to be reflected in their minds, as in a mirror, and gave to the reflected image the name of *explanation* or theory. Such men are indeed still to be found, but only in those departments of science which have not yet acquired a truly scientific foundation; and in which, partly for convenience, partly from a deficiency of logic, such speculations are tolerated. The whole science of physiology long rested on such fanciful notions or theories; and the true progress of that important science only dates from a very recent period, when its cultivators began to emancipate themselves from the fetters of speculation.

The true theorist is not the advocate of an opinion; he does not give us, instead of an explanation, the image which he has formed in his own fancy of a phenomenon or natural process; but he endeavours to ascertain by observation and experience, all those conditions which have co-operated to produce the phenomena; and in the course of his researches he tests every conclusion

at which he arrives, or every opinion which guides him, by *experiment*. When he has learned all the conditions, he then shows, always by experiment, that he can produce the result or phenomenon at will by the co-operation of these conditions in the due space of time; and this, not once nor ten times, but as often as he pleases, and invariably with the same result.

All his success depends on the continual attention which he pays to all the natural laws concerned. When he allows himself to be guided only by these, and not by mere fancies or imaginations, then, if his method of research be a just one, experiment always tells him the truth, and becomes the faithful guide and leader of his mind; it tells him that he has gone astray, or that he is in the right path.

If by *experience* we mean practice, then the theoretical chemist must be an experienced man; for he must know, practically, the laws of nature, and practically also the methods of investigating these, and the principles of their application.

Theory comprehends the *doctrine* of the natural laws, and the rules and principles which are attached to their co-operation. *Practice* is the *application* of this doctrine, the employment of these rules and principles.

For most of the methods used in obtaining chemical products, in the arts and manufactures, and the improvements of these, as, for example, the manufacture of sulphuric acid, of soap, of glass, the extraction of metals from their ores;—for these things we are indebted to chemists, who had practically studied the natural laws, the rules and principles, on which these operations depend. That is to say, we owe these processes and improvements to men who had investigated the theory of the production of these substances, without ever having been engaged in their manufacture. Such men as Davy, Gay Lussac, Berzelius, and Chevreul, were or are theorists, but at the same time practical chemists in the strictest sense of the words: they were practical men in their science. The *technical* chemist, who knows the theory of the various manufactures, teaches how to apply rightly their rules and principles in special cases.

The manufacturer and artisan applies only a small number of the thousands of natural laws, included in scientific chemistry, to the production of articles of commerce. His adviser in special cases is the technical chemist, who makes, or has already made, such cases the object of his investigations.

The price, or commercial value of substances and materials which take a part in chemical processes and manufactures, is no object of scientific research, and cannot therefore be included by the theoretical chemist in his teaching. This price is the principal factor, which determines the producer of the commercial article in his choice among the numerous ways and means for putting in practice the rules given him, that is, practically, in the production of his goods. This factor varies *ad infinitum* according to countries and localities; it depends on external things; such as means of transport (roads, canals, railways); and the proper practice of the producer, who under all circumstances must purchase labour and raw material, and sell his produce advantageously, consists, therefore, not only in the right employment of scientific principles, but also in the proper selection of those ways and means, which enable him to supply his produce in the shortest time, in the largest quantity, and at the lowest price.

Whatever process he may prefer, it is absolutely certain, that, in order to attain his object, he must in no way, and in no circumstances, act in opposition to the natural laws, fundamental principles and rules, which theory teaches. For a profitable

manufacture is only possible if these rules and principles be followed, and any deviation from them must affect injuriously certain parts of the manufacture, and in general the time of production, the quantity or the quality of the commercial article.

Since the producer is at the same time a merchant, and one who puts in practice scientific principles, it is easy to see, that the maximum of profit which a trade, a manufacture, or an art can yield, depends essentially on the combination of two kinds of talent. With a man, whose mercantile abilities are distinguished, and are equalled by his knowledge of scientific principles and his technical dexterity, no one, in a similar local position and with similar connections, can at all compete, who possesses these qualifications united in a lower degree. It is obvious, that a predominating mercantile tact, combined with order and economy, may often in a high degree compensate for, or cover, the want of scientific knowledge, but that the highest scientific endowments cannot make up for the want of mercantile ability. I know manufacturers who carry on and yearly increase their business, while employing very bad methods of production, while other men, of high scientific attainments, in a like position are ruined, because they have no sense

for order, and being ignorant of commercial habits, they cannot give a numerical expression to the values of time and labour; in a word, because they do not know how to calculate. This is too often seen, and it has led many to the conviction, that scientific knowledge is of little importance in the manufacturing arts. Such notions are principally found among farmers, who forget that it is not capital, but the human intellect, which sets it in motion in the right way, that makes the profit; and that scientific principles are the profit derived from many thousands of human intelligences, which become so many willing and dexterous servants to our intellect, if we only appropriate them.

From what has been said, it will appear, that a practical chemist (by which term I understand not a manufacturer) can be neither a theoretical, nor a practical, nor even an unpractical agriculturist or manufacturer, simply because he is no manufacturer at all.

The search after ways and means of producing any product, which is at all producible by chemical or natural forces, presupposes an acquaintance with the properties and behaviour of all those natural substances, which present themselves as capable of yielding such a product. The chemist searches

for them, and places together all such as are proper for the desired object, without being guided in his researches by the unknown factor of price, because he knows that a method of production, which is to day impracticable, on the great scale, on account of high price, may not only become to-morrow practicable, but may possibly supplant all the other methods hitherto employed.

The property of destroying organic colours, which apparently belongs to the most different substances, is referred by the chemist to the action of oxygen. He shows, that the action of air, light, and moisture may be replaced by that of chlorine gas, bleaching powder, chromic acid, or a mixture of red prussiate of potash, and caustic potash. Organic colours may be bleached by any of these means, but they differ greatly in price, and on this account cannot replace each other in the different bleaching processes. But it does not thence follow, that one of these methods may not, under certain circumstances, be preferable to another, and that the dearest of them, in this case, may not, on account of its peculiar chemical character, replace the cheapest, as we know, in fact, to be the case in calico printing.

In like manner, the use of chromic acid as an

oxidising agent, of phosphorus for matches, of stearic acid for candles, of sulphuric acid for separating gold from silver, of sulphate of soda in glass making,—all these valuable processes were scientifically demonstrated long before it was possible to employ them profitably for the production of manufactured goods. And if the properties and behaviour of these substances, and their capability of being used for this purpose, had not been made known by the labours of scientific chemists, it would hardly have occurred to any manufacturer or artisan to bring them into use at the most favourable time. Such of them as were the first to make use of these means have, as a general rule, also derived the highest profit from doing so; these are the true "practical men," who, knowing the doctrines and principles concerned, search for and discover methods of rendering them profitable. Those to whom, in ordinary life, the name of "practical men" is given, are generally such as are altogether incapable of doing this, because they are ignorant of scientific doctrine, which they regarded as unproductive, and which they consequently neglect or despise. Such a man, however, is properly nothing more than a workman who works according to a recipe, no matter whether

he has made it for himself or obtained it from others.

The true practical man deduces, in agreement with the theory, which he knows, and which sharpens his powers of observation and guides his intellect, the most profitable method for every different case as it occurs, and he renders the most unfavourable circumstances more propitious to his objects in the shortest time and at the lowest cost.

The preceding remarks may perhaps serve to place in a clearer light than is usually done the true position of chemistry and of the chemist in relation to agriculture and to the agriculturist; and if the chemist is guilty of errors and blunders in the judgment he forms of agricultural matters, he should not be too severely taken to task for these, because he must rest his conclusions in such cases on facts which he cannot know from his own experience, but must receive as accurate and trustworthy from the writings of agriculturists.

In order that the reader may the better judge of the application of chemistry to agriculture, I think it advisable to premise a statement of my views, in a few short propositions, before I enter on the consideration of the experiments and opinions of Mr. Lawes.

The growth of a plant is preceded by a germ, which is contained in the seed. Land plants require a *soil;* and without *air* and *moisture* no plant can grow. The words soil, air, and moisture are not in themselves an expression of necessary conditions, for there are calcareous, clay, and sandy or siliceous soils, soils derived from granite, gneiss, clay slate or mica slate, and others, which are very different in their composition and quality. The word soil is a collective term for a large number of conditions; a fertile soil contains these in the due proportion required for the nourishment of plants; in a barren soil, some one or more of these conditions are wanting. In like manner, the words *manure* and *air* include a plurality of conditions. The chemist, with the means at his disposal, analyses all kinds of soils; he analyses also manures, the air and water; he decomposes the collective terms which express the sum of the necessary conditions into a number of single conditions, and in his explanations he substitutes these in their proper place, for the collective terms. Now it is easy to see that in all this there is nothing hypothetical. If it be an established truth, that soil, air, water, and manure exert an influence on the growth of plants, it is no less certain that they can only do this by means of their

constituent parts; and the duty of the chemist is to make known, to the man who is occupied in the culture of plants, these constituents, their properties, and their chemical action or behaviour.

I now proceed to lay down the following propositions, which contain the views I hold and have taught on this subject.

1. Plants in general receive their *carbon* and *nitrogen* from the air, the carbon in the form of *carbonic acid*, the nitrogen in that of *ammonia*. The *water* (and ammonia) yield to plants their *hydrogen*; the *sulphur* of those parts of plants which contain that element, such as the sanguigenous bodies, is derived from *sulphuric acid*.

2. On the most diversified soils, in the most varied climates, whether cultivated in plains or on high mountains, *plants invariably contain a certain number of mineral substances, and, in fact, always the same substances; the nature and quality, or the varying proportions of which are ascertained by finding the composition of the ashes of the plants.* The mineral substances found in the ashes were originally ingredients of the soil; all fertile soils contain a certain amount of them; they are never wanting in any soil in which plants thrive.

3. In the shape of the agricultural produce of a

field, or in the crop, the entire amount of these ingredients of the soil which have become ingredients of the plants, are removed from the soil. The soil is richer in these matters before seed-time than after harvest; or, in other words, *the composition of the soil after harvest is found to be changed.*

4. After a series of years, and a corresponding number of harvests, the fertility of the soil or field diminishes. While all the other conditions have remained the same, the soil alone has not done so; it is no longer what it was at first. *The change which is found to have taken place in its composition, is the probable cause of its diminished or lost fertility.*

5. *By means of solid and liquid manure, or the excreta of men and of animals, the lost or diminished fertility of the soil is restored.*

6. Solid or farm-yard manure consists of decaying vegetable and animal matters, which contain a certain proportion of the constituents of the soil. The excrements of men and animals represent the ashes of the food consumed, that is, oxidised or burned in the bodies of men and animals; food derived from plants which have been reaped on the supposed soil. The urine contains the soluble, the solid excreta the insoluble, constituents of the

soil derived from the crops used as food, and reaped from the soil. It is clear, that by adding manure, or liquid and solid excreta to the soil, that soil recovers those constituents which have been removed from it in the crops. Thus, the restoration of its original composition is accompanied by the restoration of its fertility. It is therefore certain, that *one of the conditions of fertility in a soil is the presence in it of certain mineral constituents.* A rich, fertile soil contains more of these than a poor, barren one does.

7. The roots of plants, in regard to the absorption of their atmospherical food, behave like the leaves; that is, they possess, like these, the power of absorbing carbonic acid and ammonia, and of employing these, in their organism, in the same way as if the absorption had taken place through the leaves.

8. The *ammonia* which is contained in, or brought by means of rain, &c., into, the soil, *plays the part of a constituent of the soil.* This is true, likewise, of the *carbonic acid* in the soil.

9. Vegetable and animal matters, and animal excreta, when in the soil, undergo putrefaction and decay, or slow oxidation. The nitrogen of their nitrogenised constituents is changed, in the

processes of putrefaction and decay, into *ammonia;* and a small part of this ammonia is converted into *nitric acid,* which is the product of the oxidation or decay of ammonia.

10. There is every reason to believe, that in the process of nutrition of plants, nitric acid can replace ammonia as a source of nitrogen; that is, its nitrogen can be applied, in the vegetable organism, to the same purposes as that of ammonia.

11. In animal manure therefore, not only are plants supplied with the mineral substances which the soil must yield, but they are also supplied with those parts of their food which the plant obtains from the atmosphere. This latter supply is a clear addition to that which the air at all times affords.

12. The solid and liquid parts of the food of plants contained in the soil, enter the organism of the plant through the roots; their introduction is effected by means of *water,* which gives to them solubility and mobility. Many dissolve in pure water, others only in water which contains *carbonic acid,* or some *salt of ammonia.*

13. All those substances which render soluble those constituents of the soil which are by themselves insoluble in water, have this effect when present in the soil, that they cause the same volume

of rain water to take up and introduce into the plant a greater quantity of these constituents.

14. By the progressive decay of animal manure, the animal and vegetable remains of which it chiefly consists are converted into carbonic acid and ammoniacal salts, and thus constitute an active source of carbonic acid, which renders the air and the water which pass through the soil richer in carbonic acid than they would be without the presence of these remains.

15. Hence, animal manure not only supplies the plants with a certain amount *of their mineral and atmospheric food*, but also provides them, in *carbonic acid* and *ammoniacal salts*—those substances which are the most indispensable for the *introduction into the vegetable organism of the mineral constituents which by themselves are insoluble in water;* and this to a larger amount in the same time than could be effected without the cooperation of decaying organic matter.

16. In warm, dry seasons, plants receive from the soil less water than they do, in the same circumstances, in wet seasons. The harvest in these different seasons is in proportion to this variable supply. A field of the same quality yields in dry years a smaller crop, which increases in more moist

seasons; and, if the average temperature be the same, it increases, up to a certain limit, with the amount of rain.

17. Of two fields, of which the one contains more food for plants of all kinds, taken together, than the other, the richer yields, even in dry seasons, a higher produce than the poorer, other circumstances being the same.

18. Of two fields, of equal quality, and containing equal amounts of mineral constituents adapted to vegetable growth, but one of which contains *a source of carbonic acid*, in the form of decaying organic matter or manure, that one, even in dry years, yields more produce than the other.

The cause of this difference or inequality in the crop, in such cases, is to be found in the unequal supply of mineral constituents, both as to quantity and quality, which the plant obtains from the soil in equal times.

19. All things which oppose or impede the solubility, and consequently the absorbability, of those parts of the food of plants which occur in the soil, diminish in the same proportion the power of these substances to nourish the plant, or, in other words, render the nourishment inefficacious. A certain physical or mechanical quality or state of the soil

is a necessary condition to the efficacy of the food which is present. The soil must admit the free passage of air and water, and allow the roots to spread on all sides in search of food. The term *telluric conditions* comprises all such conditions as depend on the mechanical quality of the soil and on its chemical composition, and are necessary to the development of plants.*

* According to an excellent article in the supplement to the *Augsburg Allgemeine Zeitung* of 28th October, 1854, it appears that, to many persons, the question whether manure only exalts the physical powers of the soil, or serves also, by its constituents, for the nutrition of plants, still requires to be solved. The expression "physical powers" makes the answer difficult, because we do not know what is meant by it. The constituents of a fertile soil have many properties, among which some are physical, by which we understand such as are cognisable by our senses, as colour, density, porosity, stiffness, or lightness. To the other class of properties of the soil, not cognisable by the senses, belong the chemical characters, by which we mean, those properties which accompany chemical combination or decomposition. The absence or the presence of the physical properties impedes or promotes the manifestation of the chemical ones, that is, the processes of chemical combination and decomposition; but considered by themselves, they produce no effect. By the term "nutrition of a plant," we understand the increase of its mass in all its parts. Increase of mass is increase of weight, which can only be effected by the assimilation of ponderable particles. A substance contributes to the nutrition of a plant, or, in other words, contributes, while becoming a constituent of an organ or organs of the plant, by its own mass to this result, that the weight of the plant is increased. It is easy to see that the physical properties of matter by themselves have no direct share in this nutrition. A soil may possess the very best physical qualities and yet be barren: in order to be fertile it must contain substances of certain chemical properties, and its physical

20. All plants, without exception, require, for nutrition, *phosphoric acid, sulphuric acid, the alkalies, lime, magnesia, and iron.* Some important genera require *silica.* Those which grow on the sea-shore and in the sea, require *common salt, soda,* and *iodides of metals.* In some genera, the alkalies may be, in part, replaced by lime and magnesia, or these latter by the alkalies. All these substances are included in the term *mineral food of plants.* Carbonic acid and ammonia are the *atmospheric food* of vegetables. Water serves both as a nutritive substance, and, as a solvent, is indispensable to the whole process of nutrition.

21. The different substances necessary to the growth of a plant, or the different articles of their food, are *all of equal value;* that is to say, if one out of the whole number be absent, the plant will not thrive.

character must be such as to allow these chemical properties to be manifested. If the soil, from being very stiff, does not allow the roots to spread, the roots cannot reach the substances which they require as food. If it do not permit water to percolate through it, the nutritious substances cannot reach the roots. A piece of meat, as everybody knows, possesses nutritive properties, but it does not nourish by means of its physical properties, its colour, the strength of its fibres, or its cohesion, but because its parts are capable of becoming constituents of the living body. If we lay a piece of meat on the stomach externally, it has no effect, but must be first introduced into that organ, where it is dissolved, and so enters the circulation.

22. The soils which are proper for the cultivation of all sorts of plants, contain all the mineral constituents necessary for these plants. The words *fertile* or *rich*, *barren* or *poor*, express the relative quantities or qualities of these mineral substances present in the soil.

By difference *in quality*, we understand the unequal state of solubility, or capacity of entering the vegetable organism, in the mineral constituents, which entrance is effected by means of the solvent power of water.

Of two soils which contain *equal* quantities of mineral constituents, one may be considered rich or *fertile*, the other poor or *barren;* if in the latter, these constituents are not free or available, but in a form of combination which renders them insoluble. A substance, chemically combined with another, in consequence of the attraction between its elements, opposes a resistance to any other substance tending to combine with it; and this resistance must be overcome, if the new compound is to be formed.

23. All soils adapted for culture contain the mineral food of plants in these two states. The whole, added together, constitute the capital of the soil; and the available or soluble portions form the floating or moveable capital.

24. To improve, enrich, or fertilise a soil by proper means, but without adding to it any mineral constituents, is to render moveable, soluble, available for the plant a part of the dead or immoveable capital of the soil.

25. The mechanical preparation of the land has for its object to overcome the chemical resistance in the soil, or to render soluble and available those mineral constituents which are in chemical combination, and thence insoluble. This is effected by the aid of the air, of carbonic acid, of oxygen, and of water; and the effect is called the weathering, or action of the weather on the soil. Stagnant water in the soil, which excludes the air from access to the insoluble compounds, is an obstacle or resistance to the weathering.

26. *Fallow* is the time during which this weathering takes place. During fallow, carbonic acid and ammonia are conveyed to the soil by the rain and the air; the ammonia remains in the soil, if substances be present in due proportion which deprive it of its volatility by combining with it.

27. A soil is fertile for a *given kind* of plant when it contains the mineral food proper to that plant in due quantity, in just proportion, and in a form adapted to assimilation, or available for the plant.

28. When such a soil, by a series of crops grown on it without any replacement of the mineral substances removed in those crops, has become barren for that kind of crop, it becomes, after one or more years of fallow, again fertile for the same plant, provided it contained originally, besides the available mineral food removed, a certain amount of the same substances in an insoluble form, which have been rendered available during the fallow time, by ploughing and weathering. *Manuring with green crops* enables us to attain the same object in a shorter time.

29. Land, on which these necessary mineral constituents are not present in any form, cannot be rendered fertile by fallow or by ploughing.

30. The increase of fertility in a soil by fallowing and mechanical preparation, *if the mineral matters removed in the crops be not restored to the soil*, produces, sooner or later, a permanent barrenness.

31. If the soil is to retain *permanently* its fertility, the mineral constituents removed in the crops must be restored to it from time to time, at shorter or longer intervals, or, in other words, the original composition of the soil must be restored.

32. Different kinds of plants require for their

development, in some cases, the same mineral substances, but in unequal quantities, or in unequal times. Some cultivated plants must find soluble silica in the soil.

33. When a given piece of land contains a certain amount of all the mineral constituents *in equal quantity* and in an available form, it becomes barren for any one kind of plant when, by a series of crops, one only of these constituents—as, for example, soluble silica—has been so far removed, that the remaining quantity is no longer sufficient for a crop.

34. A *second kind* of plant, which does not require this constituent, for example, silica, may yield, on the same soil, after the former has ceased to thrive, one or a series of crops, because the other mineral substances necessary for it are present,—no longer, indeed, in the same proportion as at first, no longer in equal quantities, but in quantities sufficient for its perfect development. A *third sort* of plant may thrive on the same soil after the second, if the remaining mineral constituents suffice for a crop of it; and if, during the cultivation of these crops, a new quantity of the substance wanting for the first—for example, of soluble silica—has been rendered available by weathering, then, if the

other necessary conditions be fulfilled, the first crop may again be grown on the same land.

35. On the unequal quantity and quality (solubility, &c.) of the mineral constituents, and on the unequal proportions in which they are required for the development of the different cultivated crops, depends the *rotation of crops*, and the varieties of rotation employed in different localities.

36. The growth of a plant, its increase in mass, and its complete development in a given time, all other conditions being equal, are in proportion to the surface of the organs destined to absorb the food of the plant. The amount of the food obtainable from the air depends on the number and surface of the leaves; that of the food obtainable from the soil depends on the number and surface of the root fibres.

37. If, during the formation of the leaves and roots, two plants of the same kind are supplied with *unequal* amounts of food in the same time, their increase in mass is unequal. It is greater in that plant which, in that time, received more food: its development is accelerated. The same inequality of increase in mass is observed, when the same food is supplied to both plants in equal quantity, but *in different conditions of solubility.*

By supplying any plant with the due amount of all the atmospheric and telluric constituents necessary to its nutrition, in the required time and in the proper forms, its development in a given time is accelerated. The conditions which *shorten the time* required for its growth are the same as those which determine its *increase in mass.*

38. Two plants, whose root fibres have an *equal* length and extent, do not thrive so well beside each other, or in succession, as two whose roots, being of *unequal* length, receive their food from different strata or depths of the soil.

39. The nutritive substances, necessary to the life of a plant, must act together within a given time if the plant is to attain its full development in that time. The more rapidly a plant is developed in a certain time, the more food it requires in that time. Thus, annual or summer crops require, in the same time, more food than perennial plants.

40. If one of the co-operating constituents of the soil or of the air be absent or deficient, or do not possess the proper form or state, the plant is either not developed, or only imperfectly developed in its parts.

The *absence or deficiency*, or the want of available form, in that one constituent, renders the others

which are present *ineffectual*, or diminishes their efficacy.

41. If the absent or deficient substance be added to the soil, or, if present, but insoluble, be rendered soluble, the other constituents are thereby rendered *efficient*.

By the deficiency or absence of *one* necessary constituent, all the others being present, the soil is rendered barren for all those crops to the life of which *that one* constituent is indispensable. The soil yields rich crops, if that substance be added in due quantity and in an available form. In the case of soils of unknown composition, experiments with individual mineral manures enable us to acquire a knowledge of the quality of the land and the presence of the different mineral constituents. If, for example, phosphate of lime, given alone, is found efficacious, that is, if it increases the produce of the land, this is a sign that that substance was absent, or present in too small proportion, whereas there was no want of the others. Had any of these other necessary substances been also wanting, the phosphate of lime would have had no effect.

42. The efficacy of all the *mineral constituents of the soil* taken together, in a given time, depends on

the co-operation of the *atmospheric constituents* in the same time.

43. The efficacy of the *atmospheric constituents* in a given time, depends on the co-operation of the *mineral constituents* in the same time; if the latter be present in due proportion and in available forms, the development of the plants is in proportion to the supply and assimilation of their atmospheric food. The quantity and quality (available form) of the mineral constituents in the soil, and the absence or presence of the obstacles to their efficacy (physical qualities of the soil), increase or diminish the number and bulk of the plants which may be grown on a given surface. The *fertile* soil takes up from the air, in the plants grown on it, *more* carbonic acid and ammonia than the barren one; this absorption is in proportion to its fertility, and is only limited by the limited amount of carbonic acid and ammonia in the atmosphere.

44. With *equal supplies of the atmospheric conditions* of the growth of plants, the crops are in direct proportion to the amount of *mineral constituents* supplied in the manure.

45. With *equal telluric conditions*, the crops are in proportion to the amount of *atmospheric constituents* supplied by the *air* and the *soil* (including

manure). If, to the available mineral constituents in the soil, ammonia and carbonic acid be added in the manure, the fertility of the soil is exalted.

The union of the *telluric* and *atmospheric* conditions, and their co-operation in due quantity, time, and quality, determine the *maximum* of produce.

46. The supply of more atmospheric food (carbonic acid and ammonia, by means of ammoniacal salts and humus) than the air can furnish, increases the efficacy of the mineral constituents present in the soil, in a given time. From the same surface there is thus obtained, in that time, a heavier produce—perhaps in one year as much as in two without this excess of atmospheric food.

47. *In a soil rich in the mineral food of plants* the produce cannot be increased by adding more of the same substances.

48. *In a soil rich in the atmospheric food of plants,* (rendered so by manuring), the produce cannot be increased by adding more of the same substances.

49. From land rich in the mineral constituents, we may obtain in one year or for a series of years, by the addition of ammonia alone (in its salts) or of humus and ammonia, rich crops, without in any

way restoring the mineral substances removed in these crops. The duration of this fertility then depends on the supply, that is, the quantity and quality of the mineral constituents existing in the soil. The continued use of these manures produces, sooner or later, an exhaustion of the soil.

50. If, after a time, the soil is to recover its original fertility, the mineral substances extracted from it in a series of years must be again restored to it. If the land, in the course of ten years, has yielded ten crops, without restoration of the mineral substances removed in those crops, then we must restore these, in the eleventh year, in a quantity tenfold that of the annually removed amount, if the land is again to acquire the power of yielding a second time, a similar series of crops.

The preceding fifty propositions are all contained in one proposition; namely, that the nutrition, the growth, and the development of a plant depend on the assimilation of certain bodies, which act by virtue of their mass or substance. *This action is within certain limits directly proportional to the mass or quantity of these substances, and inversely proportional to the obstacles or to the resistance which impede their action.* If this proposition, the truth of which

is beyond all doubt, be accepted, the whole of the above fifty propositions may be deduced from it, if for the relations of quantity we substitute the words rich or poor, fertile or barren, and if, for the action or efficacy of the substances employed, we use the words fertility, produce or crop, &c.

Any one who will take the trouble to read my work with some attention, will readily find these different propositions, with the exception of No. 14, to which I shall afterwards return.

With regard to the truth of the views here developed, the good effect of animal excreta, and of animal and vegetable refuse, has been known from time immemorial. The first observations on the effect of ammonia were made, I believe, by Sir H. Davy. (See p. 67 of my work.) The study of the processes of the decay and putrefaction of animal matters, (see my memoir in the "Annalen der Chemie und Physik," vol. xxx. pp. 250 and 339,) and my observations of the *constant* presence of ammonia in the air and in rain water, led me to the conclusion that nature supplied to plants not several, but only one compound of nitrogen as food; that ammonia was the only really known and efficient nitrogenised compound, and that all other nitrogenised compounds only acted in so far as they

are capable of yielding ammonia by their decomposition in manure or in the soil.*

That humus, in presence of air and moisture, became a source of carbonic acid, was long ago proved by De Saussure. Strangely enough, De Saussure, till his death, denied the action of humus as a source of carbonic acid, and sought for proofs in favour of the so-called humus theory ("Annales de Ch. et de Ph.," vol. xlii., p. 675).

To the action of humus as a source of carbonic

* The extent of what was known, in 1840, concerning ammonia as the source of nitrogen in plants, will perhaps appear more distinctly from a letter which M. Boussingault, an authority whom no one will dispute, wrote to me, dated 8th May, 1840:

"M. Pelonze has told me that you have found carbonate of ammonia in rain-water, and that you explain the useful action of gypsum with reference to this fact (as fixing the ammonia in the form of sulphate). I agree with you in this opinion; and, moreover, I perceive herein the most important source of the nitrogen in our crops; a source which I have in vain sought for, and which I could only refer to the atmosphere generally, without being able to specify it more particularly."

Among the isolated observations of the presence of ammonia in the atmosphere is that of Scheele, who found that a crust of ammoniacal salt formed round the mouths of bottles containing hydrochloric or sulphuric acids, when put by in ordinary rooms ("Opuscula," ii. 273). De Saussure observed ("Ann. Gehlen," iv. 691), that sulphate of alumina, exposed to the air, passed into ammoniacal alum. Collard de Martigny found ("Jour. de Ch. Medicale," iii. 576) that diluted sulphuric acid, exposed to the air on a roof in Paris, after some time, contained ammonia. The experiments of Faraday, mentioned in my work, prove the same fact. I myself found ("Ann. de Ch. et de Ph." lxv. 329) that 17 out of 77 falls of rain contained nitric acid, combined with ammonia and lime.

acid, as a solvent for phosphate of lime and earthy carbonates, I first drew attention in 1851 in my "Chemical Letters" (p. 625, 3rd German edition, note). See the 14th proposition above. In 1852 Boussingault occupied himself with the determination of the amount of carbonic acid in the air contained in the pores of the soil, and found, that in soil recently manured, the air frequently contained four hundred times as much carbonic acid as the general atmosphere.

I alluded to the solubility of phosphate of lime in sulphate of ammonia in my work (p. 158). Kuhlmann expresses himself on this subject as follows, some years later ("Comptes Rendus," vol. xvii., p. 1118 to 1130). "In order fully to appreciate the effect of ammoniacal salts, it is necessary to point out, that they promote the entrance of mineral salts into the plant. Phosphate of lime, phosphate of magnesia, and silica can by the aid of carbonate of ammonia become somewhat soluble and absorbable. Every soil contains carbonate of lime, which is rarely free from alkalies, and this, under the influence of solar heat, will decompose sal ammoniac, and sulphate of ammonia, by which means soluble salts of lime, and carbonate of ammonia are produced. Hence the ammoniacal salts are not only the chief

source of nitrogen for plants, but also the means of facilitating the entrance into the vegetable organism of those mineral salts which are absolutely indispensable to its growth. No wonder, therefore, that they act so favourably." The state of solubility or available form in the mineral constituents, has, as I endeavoured to explain in my work, the greatest influence on their efficacy; and this is, for example, the reason why the hard, compact, and not porous apatite, in equal quantity, exerts a far less effect in the same time than burnt bones; and why the effect of the latter is so greatly increased when they are rendered more soluble by means of sulphuric acid.

The necessity of attending to all these conditions and relations, renders the determination of the value of any manure so difficult a problem as we find it to be; because it may be, in a certain form, apparently inactive, and in another, in the highest degree efficacious.

With regard to the necessity of the alkalies, the alkaline earths, phosphoric acid, and sulphuric acid, for all plants, and of silica for grain crops, we have already most decided and convincing proofs in the researches of Pollstorf, of the Prince of Salm Horstmar, of Magnus, of Wolf and others. No

chemist, no vegetable physiologist, in short, no scientific man, who knows how to appreciate the logical value of facts, doubts the truth of this doctrine. The doctrine itself, as is well known, is not yet old, for even so late as 1840, Dumas, in his "Statique chimique des êtres Organnés," obviously founding his opinions on the experiments of De Saussure, regarded their presence in plants as accidental.

In the "Annalen der Chemie und Physik," vol. xxxvii. p. 226, I have recorded my opinion of the views entertained by Sprengel on these substances, and the share they take in vegetation. For the most important part of what we know concerning the occurrence in plants of the mineral constituents and their significance, indeed for all that was known of vegetable physiology and agricultural chemistry before 1840, we are indebted to the investigations of De Saussure ("Recherches sur la Végétation"), and to the work of Davy, the value of both of which I have fully acknowledged. That which up to the time referred to had taken its place in botanical and agricultural works, was only a scanty abstract of these admirable researches. The benefit derived from the use of wood ashes as manure has been longer known, for Hales (in his "Vegetable Statics,"

London, 1727) enters into full details on this subject, nearly one hundred and thirty years ago.

During the years 1845 to 1849, I made a series of experiments on the action of the different mineral manures, on a considerable scale, on a piece of land of about ten English acres, which I purchased with this object from the town of Giessen. Previous experiments, which I had made in my garden in the town, had yielded no result. Whatever I did, or whatever I might add to the soil, I was unable to trace any perceptible effect from any of my mixtures. The only cause which I could discover for this apparent want of efficacy was the composition of the soil of my garden, which, by previous cultivation and manuring, had become in itself so rich in available mineral constituents, that the addition of a relatively insignificant quantity of these substances, became, when compared with the amount already present in the soil, quite inappreciable. This induced me to purchase the land alluded to, a sand pit to the east of the town, which I found to surpass all others in the whole surrounding district in its nearly complete barrenness for the ordinary cultivated crops. I do not believe that, in a whole year, there grew naturally on the whole ten acres as much grass or other fodder as would have sufficed for a

single sheep. The soil is in part a light sand, in part it consists of more or less coarse quartz pebbles and thin strata of sand with some loam.

I filled with the natural soil a number of flower-pots, in which I sowed wheat, barley, and red clover, and manured each with some single mineral manure. In none of these did the plants get beyond flowering. The land therefore was of the quality adapted to the object I had in view.

Messrs. Schwarzenberg and Co., of Ringkuhl, near Cassel, were so obliging as to prepare for me, in their soda works, according to the prescriptions I gave them, a quantity of mineral manure, which was spread uniformly over the land, except a portion used as a vineyard, on which there were about two thousand vine stocks, each of which, on being planted, had a quarter of a pound of the manure mixed with the earth about its roots. On the different subdivisions of the land there were sown wheat, rye, barley, clover, potatoes, turnips, maize, topinambour; some small lots had sawdust added to the mineral manure, one had only stable manure, and another equal parts of stable manure and mineral manure. With the exception of the stable manure used for these two lots, no ammoniacal manure, and no animal substance was applied to any part of the field.

One lot had several cart-loads of forest soil from a neighbouring wood; another had a mixture of forest soil and mineral manure.

Several of the most distinguished agriculturists of the district, and among them Herr von Fernhaber, thought that I could not succeed in growing wheat or clover on this soil; and the opinions of these gentlemen with regard to my enterprise are still fresh in my remembrance. I had calculated only on a very small produce in the first year, as the soil had never before been under cultivation; but however moderate, nay poor, the harvest was, it yet surpassed that which I had anticipated. It was indispensable that some years should elapse, before the constituents of the manure could be rendered soluble, and thus diffused throughout the soil. The barley was better on the lot manured with forest soil and mineral manure than on the other: on the lot which had been manured with sawdust and mineral manure, the plants were also larger and stronger; the lot with stable manure and mineral manure yielded a crop of wheat as rich as that on any of the best of the neighbouring fields. It was the effect of the sawdust, and of the organic matter (humus) in the forest soil, and in the stable manure, which first opened my eyes to the true

action of humus and decaying organic matter in the soil (see Proposition 14), and my previous notions on the subject were thus corrected and enlarged. The crop of turnips, clover, and potatoes was, however, not yet sufficient for the keep of a cow. Only the rye and part of the potatoes were exported from the farm. I shall perhaps, at a future time, return to the description of the individual observations; and I only remark here, that, without any supply of manure from without, all the lots looked much better in the second year, and yielded a far higher produce. This fertility steadily increased, so that, in the fourth year, the lots excited the admiration and wonder of all who had known the original state and quality of the land.

I had an opportunity, four years after the commencement of my experiments, to show my little farm to the Privy Councillor von Beckedorf, President of the College of Rural Economy in Berlin, and to the State Councillor Reuning, who, by his position in Dresden, exercises so beneficial an influence on the agriculture of Saxony; and I remember with satisfaction the lively interest which they took in my experiments. In the year 1849, my former gardener, Kappes, purchased the land from me; and this industrious man, who has not the means to

buy manure, farms with profit the little property, now in good heart. He is able, with the help of a small coffee and beer trade in the summer months, to support himself and his family on it; he keeps two cows, raises annually several oxen, and has gained what has enabled him to increase the farm buildings,—and all this without ammonia or humus, by means of mineral manure alone. A farmer in the neighbourhood, Aubel, in Wiseck, wrote to me in 1853 about the land, as follows: "With us the wheat crops are very poor; but on the height (the land is called in Giessen Liebig's 'height') they have harvested from 3 fuder of rye 12 simmer; while I, from 3 fuder of the best rye have only got 5 simmer. If you were to see it, you would be astonished; it is truly wonderful."

It was only after the lapse of four years, that the mineral constituents added to the soil gradually came into action; and the land will, as may easily be foreseen, retain its present fertility, if a quantity of these mineral constituents, equal to that contained in the crops sold off the land, be annually restored to it.

The action of the several ingredients of the manure showed itself in a most striking manner, in many cases so as to excite astonishment. The

deficiency or excess of phosphate of lime and of the alkalies for root crops, of the alkaline earths for clover, and of silicate of potash for the cereal crops, could be distinctly traced in their growth. The experimental lots were as the writing on the pages of a book,—intelligible even to the uninitiated.

I have every reason to believe, that by means of the organic refuse left on the land from the crops removed (stubble, roots, leaves, &c.), in consequence of their decay, and of the action of the carbonic acid formed from their carbonaceous constituents, mineral food for plants was extracted from the original soil and rendered available, which had formerly been utterly without effect.

Since the present proprietor has been in possession, the stable manure, and the excreta obtained from the house, especially the liquid part of it, have been most carefully collected; and it is obvious that these substances have been used as manure. These ten acres, in the crops obtained from them, have shown themselves to be true condensers of carbon and nitrogen from the atmosphere; and I consider myself as perfectly justified in concluding, from my experiments, that on ordinary farms, provided we give to the soil the proper physical quality and composition, there may be, by degrees, such

an amount of ammonia collected, or condensed, as to be more than sufficient, with the available mineral constituents present in the soil, to obtain the maximum of produce for each soil. This, of course, does not exclude the feasibility of attaining a still higher produce, if we increase the proportion of mineral and atmospheric constituents in the soil.

My experiments, which cost me an outlay of 8000 florins (about £670), that being the difference between the whole expenditure and the price received for the land, prove, no doubt, that the fertilising of barren land, if its barrenness arise from a deficiency of the necessary constituents, and not merely from a bad physical condition, renders necessary an expenditure which exceeds the price of an equal extent of the most fertile land. But in this respect, I had not deceived myself. What I wished to attain was well worth this sacrifice. What I did attain was the immoveable conviction, that a time must come for agriculture when it will be pursued as an art according to scientific principles, like every other manufacture, and not by mere recipes or traditions.

For my part, I obtained by these experiments the full conviction that my doctrine included no essential error; and also, that if rightly applied, it would

sustain its character in practice. I was thus enabled to wait with patience for its results, which time alone could develope.

Agriculture is still oppressed by an influence, which, without attracting notice, closes the door against all that science can teach. This hurtful influence is exerted by *the prescribed rotation of crops*. The farmer cannot always cultivate what he ought to cultivate, nor what he may particularly wish to cultivate, but is often compelled to occupy a great part of his land with crops; the object of which is, by enabling him to keep a number of cattle, frequently both unprofitable and troublesome to him, to produce manure for his corn crops, that is, for the growth of his saleable produce. A large amount of capital in the forms of soil, labour, and money, is wasted by these living manufactories of manure.

In our time, one problem worthy the attention of the scientific agriculturist, is this: to substitute for the rotation of crops a rotation of the proper manures, by which he shall be enabled to grow on each of his fields those crops, the sale of which, according to his locality and his special object, is the most profitable to him. How vastly would the labours of the farmer be simplified, if he

could succeed in growing, on the same piece of land, the same crop uninterruptedly, without injury to the soil!

In order to carry out this idea, in which Mr. Joshua Walmesley, formerly Mayor of Liverpool, and M.P., took a most lively interest, I proposed to the farmers of England, seven years ago, to unite with me for the institution of a series of experiments. Messrs. Muspratt and Co., of Liverpool, readily undertook, at a considerable sacrifice, the preparation of mixtures, which, founded on the analyses of the ashes of plants, were calculated to supply one kind of crop with its necessary mineral constituents for a series of years. My object was to ascertain, whether, under these circumstances, the same crop could be uninterruptedly grown on the same land, without diminishing its fertility. It was absolutely impossible to know beforehand the actual effect of these mineral manures in a given time, or to determine that effect for each field or portion of land. In order to answer all these questions, it was indispensably necessary to wait for the results of the experiments themselves; and I was firmly resolved to carry out, with the aid of a number of farmers in different counties, the experiments which, at a later period, I undertook alone.

Every one knows the result of these experiments, which even at this day figure in the works of agricultural writers as an unsuccessful speculation.* Without even knowing anything of the quality of the soils, people expected results which no manure in the world could possibly realise; and were of course disappointed in their expectations. But I was the person most completely deceived; for I had ventured to believe that the principles which I had explained had taken root in the agricultural mind. My doctrine, however, had only vitality in the minds of the teachers; without whom, without the exertions of Stöekhardt and others, the agricul-

* Mr. A. von Versen, a practical farmer, says on this subject in his work, "Nature in her Operations," Dantzic, 1854, as follows:— "We do not by this mean to say that men of science have tried to deceive mankind." The same Mr. von Versen, who gives to his readers so favourable an opinion of me, applied to me, with the most amiable *naïveté*, requesting me to let him have my opinion of its value. Such books are all very like one another. I have found in it very many extracts from my work and from other good books, enough to justify the statement that it contains much that is good. He might, with a little attention, have avoided several errors; one of these I take the liberty to correct. In p. 92, he says, "Liebig says in his 'Chemical Letters,' that in the bodies of those who undergo much mental labour there is always found less phosphorus than in those of others who use only their physical force, since phosphorus is consumed in the act of thinking. He thinks, in short, that without phosphorus there can be no thought." Now, it happens that the honour of the discovery that phosphorus exists in the brain belongs not to me, but to Dr. Moleschott, and I have stated in my "Chemical Letters," p. 553, that this discovery is erroneous, and supported by no facts whatever.

turists would have been as helpless as before. That which most farmers call *doctrine* revolves among the obscure notions of crops which *enrich, or spare, or exhaust, or corrode* the soil. I know not whether, and to what extent we might have come nearer *to the scientific object of our search,* which is perhaps unattainable, and cannot, from local circumstances, at all events be equally within reach of all; but the importance of the doctrine itself, the perfect certainty we should have acquired concerning the effect of the individual constituents of manures, according to their form and quality, and concerning the necessary variations of them to meet the special geological and climatic conditions of each locality, —these things cannot be over-estimated. Of the large sums annually collected by agricultural associations, and which, in a majority of cases, are expended entirely without fixed or determinable results; of these large sums, if only a small part, during the last ten years, had been devoted to well-devised experiments in the direction I have indicated, we might now be a great way nearer to our object than we are.

When we reflect, that the sugar-works in Waghaüsel alone bring into the market yearly 600,000 lbs. of salts of potash, the whole of which comes from

the land of the beet-root growers of Baden, and that nothing is done to restore these salts to the soil; that in the north of Germany, year after year, with the aid of guano, an enormous mass of potatoes is grown, solely for the manufacture of spirits, and that, except the constituents of the guano, none of the other mineral constituents of the potatoes are returned to the land, we can have no doubt as to the ultimate condition to which these districts must sooner or later come. The stock of these other constituents in the soil may be very large, but large as it is, it is yet exhaustible.

I feel and know, that merely to *know* a thing is not enough to secure that we *do it;* and that only a new generation is fitted to promote the real progress of a science. After a few decades, matters will be otherwise. The old, deeply-rooted errors always act as obstacles, which are stronger and more powerful than a new truth. That which a man seeks, he can ultimately find only on one road, and that the true one; and if he obstinately follows another path, which must be a wrong one, how can he hope to reach the goal?

Let the able and excellent teachers of agricultural chemistry keep up the courage necessary to ultimate success. For man, in reference to mental food, is

exactly like a plant: as the plant must receive its food, not concentrated but infinitely diluted with water, if it is to thrive,—so it is with the mind of man. An abstract truth only acts upon the senses and feelings when it is presented to them properly diluted, turned on every side, and inside out, dressed, adorned, painted, and finally it resembles the germinating seed of a tree which the wind or a bird has carried into a cleft of the rock. There lies in it, as in the seed, a wonderful organic force, which gradually conquers all obstacles, as the roots of the seed when it has become a tree can cleave or raise the heaviest rock, and, as the old proverb says, "all without noise; for that which grows makes no noise."

After the publication of the last edition of my book, I had devoted myself, in the years 1846 to 1850, to researches in animal and physiological chemistry, on the nitrogenised constituents of plants, on flesh, on the causes of the motion of the juices in plants and animals, the results of which have since appeared. These labours so completely absorbed my time, that I had entirely lost sight of agriculture; and although Mr. Lawes regularly sent me his experiments, I took no notice of them, nor of others of a similar tendency. I contented myself

with saying a few words on the subject in a new edition of my chemical letters, and thought I had done what was necessary. But in 1851 a new memoir by Mr. Lawes appeared, in which he returns to his earlier experiments, and maintains the justice of his conclusions, although now in a very limited sense. Now since I find that his results and opinions have passed into German works on agriculture, and I wish to avoid every kind of controversy in my work on "Agricultural Chemistry," when I should have to prepare a new edition of it, I have thought it best, to consider the experiments and conclusions of Mr. Lawes in this Journal.*

The memoirs of Mr. Lawes, to which I now refer, appeared in the Journal of the Royal Agricultural Society of England, vol. viii. part i., and vol. xii. part i. He says, in the latter volume, p. 2, "In the course of this inquiry, the whole tenor of our result has forced upon us opinions different from those of Professor Liebig on some important points; and more especially in relation to his so-called Mineral Theory, which is embodied in the following sentence, to be found at page 211 of the third edition of his work on 'Agricultural Chemistry,' where he says, 'The crops on a field diminish or increase in exact

* Zeitschrift für Landwirthschaft, VI. Jahrgang.

proportion to the diminution or increase of the mineral substances conveyed to it in manure.' "

This last sentence, which is said to embody my so-called Mineral Theory, has been detached from its natural connection with a series of sentences, and in my work it has, therefore, a meaning quite different from that attached to it by Mr. Lawes. These sentences are as follows: (p. 210, fourth edition,) "Hence it is quite certain, that in our fields, the amount of nitrogen in the crops is not at all in proportion to the quantity supplied in the manure, that we cannot augment the fertility of our fields by supplying them with manures rich in nitrogen, or with *ammoniacal salts* alone. The crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substances conveyed to it *in the manure*."

It appears, as the reader will soon perceive, that Mr. Lawes, in the earlier years of his experimental inquiry, had before him only this last sentence, and it would seem that at that time he was not acquainted with any other sentence in my book; and as for this one sentence, he has entirely misapprehended it.

In the sentences just quoted from my book, the produce of the land is compared with the proportion

of nitrogenous matter, inclusive of mineral substances, supplied *in the manure,* and with the amount of mineral constituents, inclusive of nitrogenous substances, supplied *in the manure.*

The words "*by ammoniacal salts alone*" and "*in the manure,*" show that I never thought of excluding carbonic acid and ammonia in the manure. According to Mr. Lawes's mistaken notion of my meaning, I ought to have said, omitting the word *manure,* that "*on the contrary the fertility of the land rises and falls with the amount of the mineral substances supplied to it.*" But this I have not said.

The meaning of these sentences in my work is this: "*that ammoniacal salts alone have no effect; that, in order to be efficacious, they must be accompanied by the mineral constituents, and that the effect is then proportional to the supply—not of ammonia, but of the mineral substances.*

The following diagram will explain my meaning:

AMMONIA.	MINERAL CONSTITUENTS.	PRODUCE.
Excess.	None.	None.
Excess.	Little.	Little.
Excess.	More.	More.
Excess.	Maximum.	Maximum.

MINERAL CONSTITUENTS.	AMMONIA.	PRODUCE.
Excess.	None.	Average.
Excess.	Little.	Full.
Excess.	More.	Maximum.
Excess.	Maximum.	No more.

Mr. Lawes, from his experiments on wheat, draws the conclusion—

1. *That the mineral constituents of wheat cannot by themselves increase the fertility of land.*

2. *That the produce, in grain and straw, is rather proportional to the supply of ammonia.*

An examination of his experiments will, I believe, convey to the reader the full conviction that his experiments not only contradict these assertions, but are also the strictest and most satisfactory proofs in favour of the opinion which I expressed in the sentences above quoted, and which Mr. Lawes thinks he has disproved.

He endeavours to prove the first of his conclusions, namely, "that the produce in grain and straw is not proportional to the quantity of the mineral substances supplied" by the following experiments:—

The wheat field which was used for these experiments extended to 14 acres. It was divided into a number of equal portions, of which one was left unmanured; one was manured annually with 14 tons of stable manure; and the rest with different kinds and different quantities or artificial manures. (Vol. viii. pp. 19, 21, 24.)

The result of seven years' experiments was, that the lot manured with stable manure yielded

a produce one half higher than that of the unmanured lot; but that on the lots manured with the most varied mixtures of bone earth, bones with sulphuric acid, phosphate of magnesia, phosphate of soda, phosphate of potash, and silicate of potash, the produce did not perceptibly exceed that of the unmanured lot. Liebig's mineral manure alone was in some degree superior to the rest; for the lot manured with it yielded 184 pounds of grain and 221 pounds of straw more than the unmanured one; a result which Mr. Lawes is inclined to ascribe to the presence of a small quantity of ammonia in this manure, which ammonia, he says, he distinctly perceived by its smell. If now we inquire into the cause of the inefficacy of the mineral manures, the answer, which it is incomprehensible how Mr. Lawes should have failed to see, is at once and easily obtained by a consideration of the crops yielded by the unmanured land. This lot yielded, per acre (vol. xii. p. 16):

1844.	923	lbs. grain and	1120	lbs. straw.
1845.	1441	„	2712	„
1846.	1207	„	1513	„
1847.	1122	„	1902	„
1848.	952	„	1712	„
1849.	1227	„	1614	„
1850.	1000	„	1719	„

7 years average 1125 lbs. grain and 1756 lbs. straw.

These numbers, which express the produce of grain and straw obtained without any manure for seven successive years in the same field, show plainly that the soil was naturally so rich in available mineral constituents, of the kinds required by plants, that manuring with 4 cwt. of mineral manure per acre, a quantity which, spread over the ground and mixed with the soil to the depth of 12 inches, gives one grain to 20 cubic inches of soil, could most certainly produce no effect, or, at the utmost, a very trifling one. For, in the first year, the soil contained seven times, or about 85 per cent. more of these substances than was required for one crop. Mr. Lawes himself says (vol. xii. p. 23): "It is a remarkable fact that, from Plot 3 of this previously unusually corn-exhausted soil, we have carried from the land seven successive crops of wheat grain and of straw, without any manure whatever, and that under this treatment there are at present no signs of diminished fertility, for the average of the seven seasons collectively is about 17½ bushels of dressed corn, and about 16 cwt. of straw. Thus the results of Plot 10*a* are alone sufficient to show, that whatever the deprivation by the previous cropping, the soil still contained, relatively to the ammonia available

from natural sources, an excess of the necessary mineral constituents."

In order to appreciate properly the mistake committed by Mr. Lawes, we must recal to recollection the quality of his *unmanured* land. This land in the seventh year yielded a crop, which exceeded by 77 lbs. of grain and 599 lbs. of straw that of the first year. Without risk of error we may assume that it would have yielded, without any manure, seven more such crops; perhaps twice this number.

Supposing, then, that it contained a supply of mineral constituents, sufficient for fourteen crops in all, then the manuring of this lot with a quantity of the constituents of the ashes of such crops, equal to the mineral constituents of *one* crop, would, at the utmost, have increased the produce by $\frac{1}{14}$th; that is, by about 80 lbs. of grain and 126 lbs. of straw. This is the maximum of increase which Mr. Lawes could have expected to obtain from this land by the use of mineral manure.

Mr. Lawes then, as appears from these passages, chose for his experiments a portion of land which, on account of its being so rich in available mineral constituents, and of its other qualities, was utterly unsuited to his purpose, and which ought to have been unhesitatingly rejected, if the object was to

test the value of the mineral food of plants. And since the mineral manure, in these circumstances, could not possibly have the effect expected by Mr. Lawes, his conclusions are destitute of all foundation in logic or in facts.

The following passage which succeeds that above quoted, may serve as a remarkable instance of the train of thought and reasoning of Mr. Lawes on the subject of agricultural chemistry (xii. p. 23): "But we must not be understood to say that all soils will yield continuously 17½ bushels of grain and 16 cwts. of straw per acre, without manure; on the contrary, we know full well that they will not, and that what are termed light soils, but which, under high cultivation, give good crops of wheat, would give but a small proportion of this quantity. That the heavier ones do possess a native fertility beyond what might at first be supposed, there can be little doubt; were it not so, we should find it difficult to explain how those who sell off their land almost all its produce without return, are enabled to live and pay their rent. But what we say is, that by the ordinary methods of practical agriculture, by which any soils are made to yield a fair produce of grain and meat only for sale, their characteristic exhaustion, as grain producers, will be that of *Nitrogen*, and that

the mineral constituents will under this course, *relatively to nitrogen*, be in excess."

When these sentences are translated into the language of science, it appears that Mr. Lawes means that he does not intend to say that all soils can yield unceasingly without manure, in every crop 1125 lbs. wheat and 1756 lbs. straw; that, on the contrary, he knows certain soils, those called light soils, that is, poor in available mineral constituents, which, if very well manured, yield good crops, but if not manured, are very soon exhausted by corn crops; but that there are other soils, called heavy soils, so rich in mineral constituents, that, without any manure, they are not to be exhausted by the cultivation of corn (?). What he means to say is this; that if we take from land in the form of produce only grain and meat, which is sold off the land, and if we restore to the soil by good manuring, all that has been extracted from it of mineral constituents in the produce sold, then the loss consists only of *Nitrogen*, and the mineral constituents, *in reference to the nitrogen*, continue in excess.

That is to say, if we substantially remove from the soil only Nitrogen, the mineral constituents remain behind, and if the soil originally contained an excess of these, this excess continues!

These are certainly truths which no one will feel disposed to contest.

It is a matter of undoubted and indubitable experience, that land, of whatever quality, does not retain its capacity of yielding good crops of the same plant for an infinite series of years; but that, at the end of a limited number of years, the plant no longer thrives on the same soil.

We know, with the utmost certainty, that the cause of this loss of fertility must be looked for in a change of the quality of the land; and that it is determined by the removal in the crops of a number of mineral substances; for, of all the conditions which ensure fertility in a soil, these alone have undergone any change; all other conditions remain as before. From this, if clearly perceived, it follows unavoidably, that the regular restoration of those constituents of the soil which are removed in the crops must sustain permanently the fertility of the land. And thus, while the land, after an indefinite series of years, would have become exhausted or unfruitful, it would have continued to be fertile for an indefinite series of years, if the mineral substances removed in the crops had been annually replaced.

What principles, then, ought to guide us in the

supposed case, in which it is assumed that all the produce is sold off the land, and that the mineral constituents of that produce are to be restored to the soil in the form of mineral manure? Shall we do as Mr. Lawes did, who, in order to test the action of mineral manure, and to hit the right point, gave to one lot (vol. viii. p. 243) 770 lbs. of phosphate of lime and soda; to another, 675 lbs. of phosphate of lime and magnesia; to a third, 725 lbs. of phosphate of lime and potash; to a fourth, 560 lbs. of phosphate of lime, and 220 lbs. of silicate of potash; to a fifth, 350 lbs. of phosphate of lime, 210 lbs. of phosphate of magnesia, and 162½ lbs. of phosphate of soda, &c.; all of these being mixtures made without any understanding of the case, and without reflection, as if they had been determined by mere chance? *

Truly, in such cases, there is no other guide but logic, that is, sound common sense, which tells us,

To give to the land what we have removed from it, neither more nor less. Of course, this is on the assumption that the land is *to retain its original fertility* only, not to be rendered more fertile than

* With reference to the scientific principles by which Mr. Lawes is guided, it is worthy of notice, that in the year 1847 he manured a wheat field with 20 cwt. of rice, and a field of turnips with 160 lbs. of phosphate of lime and 5 cwt. of train oil.

before. In the latter case, the problem takes a different form.

How and by what means are we to do this? Wheat requires soluble silica or soluble silicates, phosphate of potash, a very little phosphate of lime and magnesia, with iron and sulphuric acid. The alkaline phosphates (those of potash, soda, and ammonia) are very soluble in water, as is also silicate of potash. The earthy phosphates (of lime and magnesia) and iron are insoluble in water. When all are applied to the land together, the first fall of rain effects a separation; the soluble salts are carried down in solution, for the most part out of reach of the plant, while the insoluble salts remain on the surface. What, now, is the case in stable manure? All the salts, except those dissolved in the urine, are in combination with organic matter, and are not separable from the solid parts by lixiviation with pure water, or water acidulated with carbonic acid. It is only when the organic matter decays, that these salts gradually become free and soluble in their proper solvents. It is obvious that, above all things, we must endeavour to give to the mineral substances which we add to the land such a form that they all possess nearly an equal degree of solubility, so that the

rain may not separate them. Phosphate of lime, ignited with carbonate of potash, yields a compound in which the alkali loses in great part its solubility; but it dissolves entirely, though sparingly, in water acidulated with carbonic acid. Silicate of potash, by increasing the proportion of silica, may be obtained of all different degrees of solubility. In a mixture of clay (decayed felspar) with slaked lime, left moist for some months, for example, in a pit dug in the ground, the silica becomes soluble. Sulphuric acid, so necessary as a source of sulphur, is given in the form of gypsum (sulphate of lime), and no soil is free from iron.

Mixtures, applied to the land in this form, must have the same action as belongs to the ingredients in their natural state; the only difference will be in the time required. All these substances are more or less soluble in rain water, and still more soluble in water containing a larger proportion of carbonic acid. Their full effect is obtained when they have become soluble in the course of an agricultural year; of course, if they are dissolved, and thus rendered available to the plants only in the course of two years, only half of them acts in any one year. In this case, the effect of such mixtures would be comparatively small in the first year

of their application; in the second year, after a new application, the result would be more favourable; after a third, still better, and so forth. It is necessary, if we would investigate the subject properly, to prepare, from the first, a whole series of mixtures of different solubility, and to try the action of each of these by itself on the same land. We should thus, after a year or two, easily discover which of them answered the purpose best; and the best mixture would be that which produced its full effect in one agricultural year.

Simultaneously with these experiments, others should be made with mineral manure in the liquid form, the ingredients of which are therefore entirely dissolved. There are many silicates, which dissolve in diluted sulphuric acid, or yield to that acid abundance of silicate of lime and alkalies. Even now phosphate of lime is very generally applied to the land in this form, at least in England. *Hence, the same sulphuric acid might contain, at the same time, soluble silica, phosphate of lime and alkalies;* and it is a question, whether this form of application be not preferable to all others. Of the natural silicates, *palagonite* is remarkable for its great solubility in acids, and it requires but a relatively small quantity of this mineral to restore, to a soil on which wheat

has been grown, the soluble silica which had been removed in the crops.

By a limited series of such experiments, the position of agriculture would soon be made very different from what it is; for it would be easy to make further progress, if we started from an accurate knowledge of the action of the different mineral constituents, and of their most advantageous form. I am very far from supposing that the farmer should not use, that is, apply to his land, any of the refuse of his crops, such as chaff, straw, stubble, and the like, which he has, and which may be unsaleable, although containing valuable constituents. That is not the question here; for the question which now occupies us is a purely theoretical one. The farmer must acquire the conviction, that farm-yard manure, the universal manure, and each of its ingredients, may be replaced by equivalent substances of like composition and form; and he can only acquire this conviction by ascertaining the effect of mixtures in which farm-yard manure, and all connected with it, are entirely excluded. He is then free, if he think fit, either to renounce altogether the use of farm-yard manure, or to make up the deficiencies of the different available kinds of refuse from his crops, the composition of which he has ascertained, by means

of mineral manure. He must be enabled to supply to each individual field, in approximatively just proportion, and of a proper quality or form, all the necessary constituents corresponding to, or required by, the peculiar crop which he wishes to raise. It is only when this point has been attained that the agriculturist is free from all constraint, and becomes master of those forces which are within his reach, and are applicable to the raising of his produce.

If we compare the produce of the unmanured land in Mr. Lawes's experiments, in different years, we observe a considerable difference. He obtained

In the 2nd year, 1845,	1441 lbs. grain	and	2712 lbs. straw.
In the 1st year, 1844,	925 ,,		1120 ,,

consequently in the second year 516 lbs. and 1592 lbs. more than in the first, although the land, of course, was richer in mineral constituents in the first year than in the second.

If we ask for the cause of this inequality of produce, it cannot be found in a greater amount of carbonic acid and ammonia in the air, produced in the second year by unknown causes. The true explanation must inevitably be sought for in some causes which, in the period of growth of 1845, rendered soluble and efficient a larger amount of mineral

constituents in the same time, than in 1844. Had these constituents not been present in the soil, an increased supply of carbonic acid and ammonia from the air could not have had any effect on the crop. But as we cannot suppose that the mineral constituents of the same land vary in their solubility in different years, from unknown causes,—that in one year they are more soluble than in another,—we can only point, as the probable causes of the observed variation, to the unequal amount of rain which fell in the two years, and to the temperature of the years. These causes determine the amount of water which enters the plant, and evaporates from it.

If, in the year 1844, a certain amount of rain fell on the land, and thus a certain amount of mineral constituents was rendered available for the plant; and if, in 1845, there fell, at the favourable season, one-half more rain, this obviously dissolved one-half more of mineral constituents. Had these not been dissolved, they could not have entered the plant, and been there employed; that is to say, without their aid the crop of 1845 could not have increased by one-half.

That to which, in these remarks, I wish particularly to direct the attention of farmers, is the

fact that, in this striking case, the produce of the land in grain and straw, and therefore in nitrogenised matters, was much increased, without the smallest addition of nitrogenous manure, for the land received no manure whatever; and solely from the increase in the amount of the mineral constituents, present in the soil, *dissolved in the same time.*

A larger quantity of these mineral substances became active in the same time, and the surface of the land was thus enabled, by the plants growing on it, to absorb from the air one-half more carbonic acid and ammonia than in the preceding year.

Had Mr. Lawes left one-half of the land without any manure, while he supplied the other half with mineral bodies in exact proportion to those which had been removed, and if he had grown wheat on both halves, it is probable that, after a series of years, the following state of matters would have occurred.

The produce of the unmanured half would have annually diminished, while that of the other would have continued as it was at first. I regard it as even probable, that the manured half would have increased in its produce, because, by cultivation, a small amount of the insoluble mineral matters in

the soil would have been annually rendered soluble, and therefore added to the soluble matters present. Mr. Lawes could not ascertain, in the crops which he obtained, that the mineral manures had not acted on his experiments; and, as I shall show, from his latest memoir (vol. xii. p. 39), he seems *never* to have entertained the opinion, that these mineral manures do not act at all. I do not, therefore, feel farther called on to defend the so-called Mineral Theory in the proposition which he has misapprehended. I still venture to believe, however this may surprise Mr. Lawes (vol. xii. p. 2), that this theory is incontestably true; and that in its establishment and development are included the progress and the whole future of agriculture.

If we ask for the other means, which experience and science afford, of raising to a maximum the produce of a soil which contains all the necessary mineral constituents in excess,—as, for example, that of Mr. Lawes's fields,—that is, to render the soil capable of yielding richer crops, a higher produce of grain and straw, the answer is easy. I shall, with reference to this question, allow my book to speak; and I consider it fortunate that Mr. Lawes has not consulted nor read it, because we should otherwise have been deprived of a whole

series of instructive experiments. I quote from the 4th English edition :—

P. 169, it is said: "A fertile soil must contain in sufficient quantity, and in a form adapted for assimilation, all the inorganic materials indispensable for the growth of plants."

P. 211. "Ammonia accelerates and favours the growth of plants in all kinds of soils, in which exist the conditions for its assimilation."

P. 148. "But, independently of these views, a rational farmer must endeavour to effect the purpose desired, and in doing so he must act exactly as if the presence of the inorganic constituents of blood (the alkalies and phosphates) were indispensable for the production of the organic constituents. If he is desirous of making his land yield a maximum of blood and flesh, he must *furnish to it in abundant quantity those constituents which the atmosphere cannot yield.*"

P. 167. "If we desire to produce from a given surface more of these constituents of the blood, than the plants growing on it could receive from the atmosphere or from the soil in their natural wild and normal condition, *we must procure an artificial atmosphere*, and we must add to the soil the ingredients in which it is deficient."

P. 168. "*The food contained in the atmosphere does not suffice* to enable these plants to obtain their *maximum* of size in the short period of their life. If the object of culture is to be attained, there must be present in the soil itself an *artificial atmosphere of carbonic acid and ammonia*, and this excess of nourishment which the leaves cannot get, must be conveyed to corresponding organs existing in the soil."

P. 177. "It is certainly the case that we could dispense with the excrements of men and animals, if we were able to obtain from other sources the ingredients on which depends all their value for agriculture. It is a matter of no consequence whether we obtain ammonia in the form of urine, or in that of a salt from the products of the distillation of coal; or whether we obtain phosphate of lime in the form of bones, or as the mineral apatite. The principal object of agriculture is to restore to our land the substances removed from it. If the restoration be imperfect, the fertility of our fields is impaired; but if, on the contrary, we add more than we take away, the fertility will increase. The importation of urine, or of solid excrements from a foreign land, is quite equivalent to the importation of corn and cattle; but these matters, in a

certain time, assume the form of corn, flesh and bones."

P. 53. "This ammonia is imbibed by the soil either in solution in water, or in the gaseous form, and plants thus receive a larger supply of nitrogen than is afforded to them by the atmosphere."

The advantage of this artificial supply of ammonia, as a source of nitrogen, is limited, like that derived from the presence of humus in the soil, to a gain of time.

P. 134. " If we furnish to the soil, (which contains already all the other constituents) ammonia, and to the cereals the phosphates essential to their growth, in the event of their being deficient, we furnish all conditions necessary for a rich crop, as the atmosphere forms an inexhaustible magazine of carbonic acid."

These quotations from my work leave not the slightest doubt as to the opinions entertained by myself, the author of the so-called Mineral Theory, as to the means of exalting the fertility of land, the soil of which is of a proper quality.

Mr. Lawes gave to the experimental Lot 10*a*, in the first year, 5 cwt. of bones dissolved in sulphuric acid, and 2 cwt. of silicated alkalies; in the following years only ammoniacal salts.

YEAR.	MANURE.		CROP. Grain.	Straw.
1. 1844.	Phosphate of Lime, Silicated Alkalies	As above.	1008 lbs.	1112 lbs.
2. 1845.	336 lbs. Am. Salts.		1980 „	4266 „
3. 1846.	224 „		1850 „	2244 „
4. 1847.	300 „		1702 „	2801 „
5. 1848.	300 „		1334 „	2367 „
6. 1849.	400 „		2141 „	2854 „
7. 1850.	400 „		1721 „	3089 „
Average crop in 7 years			1676 „	2689 „
Average crop of unmanured lot in 7 years			1125 „	1756 „
Average excess of manured lot . .			551 „	933 „

Mr. Lawes, acting under the erroneous impression that my views as to the conditions of fertility in land were embodied in one sentence of my work, consisting of only three lines, regards these results as irreconcilable with my doctrines, because, in the case before us, the crops were augmented during a series of years by the use of ammoniacal salts alone without any mineral constituents having been added to the soil, and that, to the extent of one half more than on the same quality of land unmanured.

In that work of mine I have fully explained that the idea of fertility in a soil, essentially comprises that of the *continuance* or *duration* of the crops. No one regards as fertile land such as, without manure, bears good crops for a year or two, and no more. In this point of view, the fertility of a soil

is in direct proportion to the conditions of fertility present in it; that is, to the mineral substances which are necessary for the nutrition of plants.

But the *quantity* or amount of produce is in proportion to *two factors*, namely, the *atmospheric* food of plants, and their *terrestrial* or *mineral* food. This quantity depends on the presence of both, and on their co-operation in due proportion, and in the proper time.

If the amount of one of these factors—the mineral food of plants—be increased, while that of the other—the carbonic acid and ammonia, which can be conveyed to the plants by means of the atmosphere—remain unchanged, the amount of carbonised and nitrogenised produce cannot thereby increase; but the crops, in this case, will vary with the absorbing or active surface of the plants cultivated on the land.

Now, since the air contains a very limited amount of carbonic acid and ammonia, for 2500 volumes (cubic feet, miles, &c.) of air contain only one volume of carbonic acid, and a far smaller proportion of ammonia, the quantity of atmospheric food conveyed to the plants essentially depends on the change of the strata of air in contact with the plants. The air which has yielded up and lost its carbonic acid and ammonia must be replaced by fresh air, if a

further absorption of these constituents is to take place. This change of air demands a certain time.

It is obvious that, if we could double or treble the proportion of carbonic acid and ammonia in the air, the plants would, in the same circumstances, take up twice or thrice as much carbonic acid and ammonia in the same time, or as much as they could do in the normal condition in twice or thrice the time. In like manner a double or treble quantity of the mineral food of plants must, in the supposed case, come into action; for, as these form part of the vegetable organism, an increase in the mass of the plant, and of course in its parts, is not conceivable without these mineral substances. By this co-operation, therefore, of the atmospheric with the mineral food, the crop will be doubled or trebled. The *duration* of fertility, or the crops obtainable in a series of years, are determined by the sum of the mineral constituents present in the soil, and in a state adapted to assimilation.

But the weight or amount of the crops is in proportion to the quantity of the food of both kinds, atmospheric and mineral, which is present in the soil, or conveyed to it in the same time. By manuring with ammoniacal salts a soil rich in available mineral constituents, the crops are augmented

in the same way as they would have been if we had increased the proportion of ammonia in the air.

This is the meaning of the passages above quoted from my work, which tell the agriculturist that, in order to raise the produce of his land above a certain point, in the case of such plants as have not many leaves—for example, of wheat—he must add ammonia in the manure.

In these circumstances, the attainment of a higher produce essentially depends on the condition that there be no want of available mineral constituents in the soil. When these last are present in excess, as is the case in very rich soils, it is quite unnecessary, indeed superfluous, to add them.

In such fertile soils, rich in available mineral food for plants, the *restoration* of the mineral constituents removed in the crops does not augment the produce, but secures their duration in a series of years.

Mr. Lawes has shown, in the most convincing manner, that in his land the mineral constituents of wheat were present in the greatest abundance and in an available form; and no one but Mr. Lawes himself can be surprised that, under such circumstances, by manuring with ammoniacal salts only, without any addition of mineral matter, he obtained during six years a higher produce than from the

same land unmanured; for theory plainly predicts such a result.

It is not easy to understand how Mr. Lawes could deduce from his results the conclusion, "*that nitrogenised manures are peculiarly adapted for the culture of wheat*," since such manures can only produce a favourable result if certain preliminary conditions, which Mr. Lawes has entirely disregarded, be fulfilled. There could hardly be made an assertion better calculated to mislead the practical farmer. I had myself, in the first edition of my work, attributed to ammonia a preponderating value and importance, and I thought I had sufficiently corrected this error in the subsequent editions.

Had Mr. Lawes asserted, that *on his land, in the given circumstances*, ammonia and ammoniacal salts were found to be peculiarly favourable to the growth of wheat; and that, leaving the price out of view, these salts, under similar circumstances, formed the best manure, he would simply have confirmed a result predicted by theory. But even if his assertion had been given as an entirely new discovery, there could have been nothing urged against it.

If, however, we extend his conclusions to any other land of *different quality*, and placed in

different preliminary conditions, it will appear *entirely erroneous;* for it can be proved, in the same way, and by facts equally decisive, that *ammoniacal salts alone,* in thousands of wheat fields, do not in the smallest degree increase the produce; and that, in thousands of other such fields, these salts do increase the produce for a year, or for two years, and that then a farther application of them to the same land is found to be utterly without effect.

The case now before us, which has led Mr. Lawes to the opinion, that the practical experience of agriculture is in contradiction to theory, is well adapted to show what are the points to be specially attended to in making agricultural experiments. To say that nitrogenised manures have a peculiarly favourable effect in the cultivation of wheat, is simply the expression of a phenomenon observed in a certain case, but the cause of which has not been further explored. The assertion is merely the fact itself, and teaches or explains nothing, because it has not been connected with, or referred to, scientific principles. Such a fact or assertion, unexplained, is an unknown quantity, $= x$; *and the object of experiment must always be to convert an unknown into a known quantity.* Innumerable

agricultural facts are so many examples of x, but thousands of unknown quantities will never make one that is known.

It is evident, from Mr. Lawes's experiments, that, by the use of ammoniacal salts as manure, supposing here that their action depends on the ammonia as a source of nitrogen alone (a supposition which I shall consider farther on), the action of the mineral constituents present in the soil, and available, is accelerated *in the time of the experiment.*

If we suppose the whole amount of the available mineral matters required by wheat in the soil of one acre to be = 12, and to suffice for twelve successive annual harvests of grain and straw, we shall have, on the supposed acre, in twelve years, twelve crops, *without the use of mineral manure, and without the use of ammonia.*

If we manure the same land with 3 cwt. of ammoniacal salts, we shall have, in one year, a crop one-half heavier than on the unmanured land; we shall obtain annually one-and-half crops, or, in eight years, the produce of twelve average crops. That is to say, the soil will have lost, in eight years, as much mineral matter as it would have lost in twelve years without ammoniacal salts: it will therefore be exhausted, or become unfruitful for

wheat, four years sooner than if no ammoniacal salts had been used.

I hold, therefore, that which in my work I have endeavoured so fully and minutely to explain, that, in reference to the exhaustion of the soil, *ammonia* or *ammoniacal salts, used alone*, are the kinds of manure which impoverish a soil, or in other words, consume the capital of the land, the most rapidly.

In one case only does the fertility of the soil manured with ammonia, or its salts, maintain itself, namely, when these are accompanied by the mineral substances which are annually removed in the crops. These may be restored either by annually adding as much as is removed, or by adding after the fifth crop a five-fold quantity of them. If this be once omitted, the effect must become perceptible in a series of years.

The rational agriculturist must not believe, that he can remove from a rich fertile soil, without any compensation whatever, a part of its constituents, and not, by so doing, sooner or later impair its fertility; for this fertility, or the produce in a given time, is the effect of the whole sum of the actions of all its constituents; not only of that portion of them, which has entered the plants, but also of the rest of the available supply, which is left in the

soil. The entire supply, or sum, has produced this result, namely, that the roots found everywhere their necessary food; and if we remove a part of the whole supply of these constituents, then the roots will no longer find their proper food in that part of the soil where they are wanting.

Let us only suppose that during the last few centuries our ancestors had acted on the principles here laid down, in their full extent and strictness; what a paradise of fertility would England be at this day! The neglect of these principles, that is, the not restoring to the land the mineral substances removed in the crops, is the true cause of the impoverishment of the land, and the source of all that poverty, the cure of which is in Germany daily rendered more difficult by the subdivision of the soil.

There is but one manure, which permanently keeps up the fertility of the land, and that is *farm-yard manure;* and when the necessities of the times compel the farmer to search for means to replace this invaluable manure in all its effects, this can only be rationally done with any prospect of success, *if we replace all its constituents.* Our first object will naturally be, to restore to the soil the mineral constituents in the same quantity and in the same proportions as those in which they have

been removed in the crops; and *none must be omitted.*

It is hence plainly incontestable, that if we cannot or do not employ farm-yard manure, and give to the soil only one of its constituents, namely, the ammoniacal salts, *the use of these ammoniacal salts necessarily compels us to add the other constituents in the form of mineral manures,* if we would keep up the fertility of the soil.

With the use of ammoniacal salts *alone,* without any mineral manure, no cultivation whatever can be *permanently* kept up, if farm-yard manure be excluded. The experiments of Mr. Lawes lead to this conclusion, and if these experiments be duly examined, the truth of what I said in the introduction, namely, "that of all experiments, none were better adapted than those of Mr. Lawes to pave the way for the so-called Mineral Theory, will be admitted.

Indeed Mr. Lawes has been himself, by his own results, in so high a degree driven, as it were, to the same conclusion, that nothing but the almost comical pertinacity with which he adheres to his original idea can explain how he has not spontaneously adopted the former. He says (vol. viii. p. 245), "For the last seven years this field has

suffered an immense loss of minerals, rendered available to the plant by means of ammonia; and the produce of last year (1846), showed that the mineral condition was still little impaired. The crop now growing shows, however, symptoms of an opposite condition of soil. In some experiments, where no minerals have been supplied, the salts of ammonia are not producing their accustomed effect; an excess of the azotised condition is commencing, and mineral manures will now have to be employed to increase the natural produce of the soil."

It would certainly have been most interesting, had Mr. Lawes described the unsuccessful experiments with ammoniacal salts in the same fullness of detail as to the amount of produce, as he has done those with mineral manure, which, according to him, were also unsuccessful; for the relations in both series of experiments were the same, only inverted, Mineral manure did not augment the produce, as long as *an excess* of mineral constituents was present in the soil; and the ammoniacal salts failed to produce their usual effects, when the soil contained these salts *in excess*.

Again: (vol. xii. p. 25,) "That the mineral constituents are indeed becoming deficient in several of the plots of our experimental fields, we have in

our collective result, as well on turnips and beans as on wheat, abundant evidence."

But the finest justification of the mineral theory is the following: (vol. xii. pp. 26, 27,) "We by no means suppose, however, that if some cheap source of ammonia were discovered, we might with impunity continuously exhaust our soils in the growth of corn by its means, but, on the contrary, fully admit that, *under such a course, our mineral supply would soon become deficient.*"

Again: (vol. xii. p. 26,) "From the above [the comparison of the produce obtained by the use of ammoniacal salts alone, and that from mineral manure with ammoniacal salts in the years 1845 to 1850], it appears that although plot 10*a*, with ammoniacal salts only, has given every year a considerable increase beyond that of the unmanured plot, yet the ammoniacal salts thus supplied were evidently much in excess over the minerals available within the soil; *for in every case where minerals have been also liberally supplied, we have in corn, straw, or both, a considerably larger increase still.*"

After these facts, it is surely superfluous to say a word more on the effect of the mineral food of plants, and especially on the mode of action of ammonia.

The mineral constituents act, as is shown by the

produce of the unmanured land, *without any artificial supply of ammonia.*

The ammonia increases the produce *only if the mineral constituents be present in the soil in due quantity, and in an available form.*

Ammonia is without effect if the mineral constituents are wanting. Consequently, the action of ammonia is limited to the acceleration of the action of the mineral constituents in a given time; and under like circumstances, the produce of soils is in direct proportion to the quantity of mineral food present in the soil, or, in the usual phrase of farmers, *to the richness of the soil.*

When we read with attention the memoirs of Mr. Lawes, all must be struck with the remarkable inequality of the style. A paragraph which plainly shows that its author knows nothing whatever of a theory, is followed by another, from which, unquestionably, we must conclude that the author possesses a knowledge of scientific principles. It is as if two persons had written these memoirs; a farmer and a chemist, one of whom did not understand the other. In addition to the specimen already given, I here quote another; both may serve to show what notions the writer had of agricultural chemistry. He says: (vol. xiii. p. 14,) "In other

words, the addition of ammoniacal salts to Liebig's mineral manure has increased the produce by very nearly 9 bushels per acre beyond that of the mineral manure alone, whilst the increase obtained over the unmanured plot, by 14 tons of farm-yard, was only 9¼ bushels."

"If then the 'mechanical form and chemical qualities' of the so-called 'mineral manure' were at fault, the sulphate of ammonia has, at least, compensated for the defect; and even supposing a mineral manure, founded on a knowledge of the composition of the ashes of the plant, be still the great desideratum, the farmer may rest contented, meanwhile, that he has in ammonia, supplied to him by Peruvian guano, by ammoniacal salts, and by other sources, so good a substitute." *

* In many experiments, Mr. Lawes, in order to ascertain, at the same time, the effect of a substance *rich in carbon*, has added to his mixtures rape seed-cake (oil-cake), as "calculated to supply a certain quantity of *carbonaceous* substance, in which both corn and straw so much abound." For his object, he could not have selected a more unfit substance; for oil-cake is one of the manures which is richest in nitrogen, and at the same time acts also favourably by its ashes (mineral constituents) on the production of grain. Oil-cake contains, according to Dr. Way, 5½ per cent. of nitrogen, and 8 per cent. of ash. The percentage of nitrogen is so high, that 100 parts of oil-cake are equal, in this respect, to 62 of good guano. Mr. Lawes throughout speaks of the action of oil-cake as of that of *the most highly carbonised manure!* It is hardly excusable that Dr. Gilbert, who lent his aid to Mr. Lawes as a chemist, did not guard him against such unpardonable blunders.

Now, every one would suppose from this, that Mr. Lawes thought that the use of ammonia enabled us to dispense with that of mineral manure, founded on the knowledge of the composition of vegetable ashes, and that these, the ashes or mineral constituents, might be replaced by ammonia. But he says: (vol xii. p. 39,) "If the theory of Baron Liebig simply implies that the growing plant must have within its reach a sufficiency of the mineral constituents of which it is to be built up, we fully and entirely assent to so evident a truism."

These two paragraphs are altogether irreconcilable; for if Mr. Lawes admit, that the mineral constituents are indispensable to plants, how can he maintain that these very mineral constituents are replaceable by ammonia, that is to say, that by means of ammonia we can altogether dispense with them?

One important fact seems to me to be established with tolerable certainty by the experiments with ammoniacal salts, and that is, that when sulphate of ammonia is used, we can dispense with the presence in the soil of a substance, rich in carbon, in a state of decay.

If we compare together the produce of the two lots manured, one with ammoniacal salts, and the other with farm-yard manure, it appears that

	Grain.	Straw.
One acre yielded with 14 tons of farm-yard manure. . . .	1826 lbs.	2454 lbs.
With Liebig's mineral manure and 2 cwt. ammoniacal salts . .	1967 „	2571 „
With different mixtures of mineral manure and ammoniacal salts, average of 7 years, Lot 2 . .	1978 „	3361 „
Ditto Lot 18*a*. . .	1922 „	3247 „
Ditto Lot 18*b*. . .	1833 „	3189 „

In these experiments, three portions of land were each manured, for seven years, with mineral manure (mineral constituents of the soil and ammoniacal salts), and yielded annually a higher produce in grain and straw than was obtained from an equal extent of land manured annually with fourteen tons of farm-yard or box manure.

It follows from this, that *farm-yard or stable manure can be replaced in its entire effect by mineral manure;* and not only replaced, for it can be, by the use of mineral substances alone (sulphate of ammonia and sal-ammoniac are mineral), surpassed in its fullest efficacy.

These facts appear to me so deeply important, because they, in entire unison with the results of chemical research, deprive the formerly prevailing views of the mode of action of farm-yard manure and of animal excreta in general, of all support or foundation. We know what that *something* is which acts

in manure, and which was so incomprehensible to the earlier writers on agriculture; and the notion, that by adding to the soil organic matter capable of giving out heat, as we see farm-yard manure does on the dunghill, we produce a warmer climate in the soil, has entirely lost all significance, if it ever had any.

It is evident, from the facts above stated, *that the organic matter in farm-yard manure, however useful it may be, can be dispensed with, and completely replaced by artificial means.* I consider these results, for the present, only as useful and advantageous in contributing to establish a scientific principle, and I readily admit, that the use of ammoniacal salts, considered with reference to its commercial value, is to the practical farmer a matter of small moment.

I have already endeavoured to reduce to its true value the action of the organic matters in manure, and to show that, by their decay, carbonic acid is formed, which, dissolved in rain water, is the indispensable condition for the entrance of the phosphates into the vegetable organism.

Now, since sulphate of ammonia and sal-ammoniac, in the same way as carbonic acid, increase the solvent power of water for these essential ingredients of the food of plants, the question at once arises, whether their good effects may not depend in great

part on *this* property; and whether, in the experiments of Mr. Lawes, the whole effect of the ammoniacal salts do not consist of two actions, namely, that of ammonia, as food for plants, as a source of nitrogen, and that of its salts as replacing carbonic acid? The answer to this question may serve to reduce to its real value the assertion of Mr. Lawes (vol. xii. p. 24), "that it would be much nearer the truth to say that the crop has risen and fallen in proportion to the diminution or increase of the ammonia supplied to it in manure."

When we inquire in what proportion the produce rose above that of the unmanured land in the experiments of Mr. Lawes, in which ammoniacal salts were used, the following facts appear:—

After previous manuring with 5 cwt. of superphosphate of lime, and 2 cwt. of silicate of potash, the lot 10*a* yielded, per acre, when manured with ammoniacal salts, in six years, 1845 to 1850, inclusive (vol. xii. p. 16):—

A. 1844.

	PRODUCE PER ACRE.	
	Grain.	Straw.
Lot 10*a*, manured, in all, with 1960 lbs. of ammoniacal salts, during 6 years	10,728 lbs.	17,703 lbs.
Unmanured Lot in the same time .	6,950 „	11,172 „
Increase from 1960 lbs. am. salts .	3,978 „	6,531 „
1 lb. of ammoniacal salts produced an increase of	1·818 „	3·34 „

While, therefore, one acre, without having received any ammoniacal salts, yielded 6950 lbs. grain and 11,172 lbs. straw, each lb. of these salts produced an increase of nearly 2 lbs. of grain, and more than 3 lbs. of straw. Mr. Lawes obtained further (vol. xii. p. 10) :—

B. 1845.

	Grain.	Straw.
Lots 9 and 10, with 672 lbs. ammoniacal salts	4111 lbs.	8324 lbs.
Lots 3 and 5*a*, unmanured . .	2872 „	5380 „
Increase from 672 lbs. ammo. salts .	1239 „	2944 „
„ 1 lb. „ .	1·84 „	4½ „

C. 1846.

	Grain.	Straw.
No. 10*a*, with 224 lbs. ammoniacal salts	1850 lbs.	2244 lbs.
No. 10*b*, unmanured	1216 „	1455 „
Increase from 224 lbs. ammo. salts .	634 „	789 „
„ 1 lb. „ .	2·82 „	3½ „

D. 1846.

	Grain.	Straw.
Liebig's manure for wheat 448 lbs. Ammoniacal salts 224 „	1967 lbs.	2571 lbs.
No. 3, unmanured	1207 „	1513 „
Increase	760 „	1058 „

			Grain.	Straw.
D. Increase from 224 lbs. ammoniacal salts, per acre, for		1 lb.	3·43 lbs.	4·7 lbs.
C. Ditto	224 lbs.	1 „	2·82 „	3·5 „
B. Ditto	336 „	1 „	1·84 „	4·5 „
A. Ditto	336 „ (average)	1 „	1·81 „	3·34 „

From these numbers, we see plainly how utterly

destitute of foundation is the above quoted assertion of Mr. Lawes; for instead of obtaining for every additional pound of ammoniacal salts an equal increase, which he must have done had his opinion been correct, he obtained on the land manured with only 2 cwt. of ammoniacal salts, from half as much again to twice as much grain and straw for each lb. of ammoniacal salts as from the land manured with 3 cwt., or half as much more of these salts.

It is thus, I conceive, demonstrated by Mr. Lawes's own experiments, that the increase in produce is not in proportion to the quantity of ammoniacal salts given in the manure, and we shall now inquire in what proportion it really stood to the supply of ammonia.

The field No. 10*a*, with 1960 lbs. of ammoniacal salts, produced for six successive years an annual increase of produce, over that of the unmanured land, of 3978 lbs. of grain, and 6531 lbs. of straw.

Now, if we take the average per centage of nitrogen in wheat at 2 per cent., and in wheat-straw at 0·4 per cent., we find by the existing analyses of wheat and wheat-straw, that these products, that is, the excess of produce annually, contained about 100 lbs. of nitrogen. This quantity of nitrogen is

contained in 430 lbs. of the ammoniacal salts employed, if chemically pure, which, however, is not a point of much importance.

If then the ammonia in these salts had acted as food for the plants, and thus yielded the increase of nitrogen in the crop, then, during six years, of the 1960 lbs. of ammoniacal salts, only 430 lbs. must have entered the plants, or in each year 72 lbs., and the whole residue of 1530 lbs. must have remained in the soil as excess. But as the whole 1960 lbs. was not added in one year, but in portions during six years, the soil became each year richer in them than it was in the preceding. There remained a residue from the previous year, which was annually increased by the portion newly added.

If we subtract from the sum of the quantities annually given to the soil the quantities annually taking a share in vegetation, or which may have done so, and which we have supposed to be removed from the soil in the increase of produce, we find that,—

	AMMONIACAL SALTS.			AM. SALTS.	RESIDUE.
	lbs.			lbs.	lbs.
In 1845, the land received	336		and there entered the plant	72	254
In 1846, „	224	478	„	72	406
Residue of 1845	254				
In 1847, the land received	300	706	„	72	634
Residue of 1846	406				

	AMMONIACAL SALTS.		AM. SALTS.	RESIDUE.
	lbs.		lbs.	lbs.
In 1848, the land received 300 Residue of 1847 634	934	„	72	862
In 1849, the land received 400 Residue of 1848 862	1262	„	72	1192
In 1850, the land received 400 Residue of 1849 1192	1592	„	72	1520

The lot yielded an excess of produce over that of the unmanured one of—

	Ammoniacal Salts.	Grain.	Straw.
In 1845	336 lbs.	539 lbs.	1554 lbs.
1846	478 „	643 „	731 „
1847	706 „	579 „	989 „
1848	934 „	382 „	655 „
1849	1262 „	914 „	1240 „
1850	1592 „	721 „	1370 „

Consequently, in the year

			Grain.	Straw.
			lbs.	lbs.
1845, 100 lbs.	ammoniacal salts	increased the produce by	160	460
1846, 100	„	„	134	153
1847, 100	„	„	82	140
1848, 100	„	„	40	70
1849, 100	„	„	73	98
1850, 100	„	„	45	86

I readily admit, beforehand, all the objections which can be made to this calculation; I admit that the ammoniacal salts may have contained from 10 to 15 per cent. of impurities, and therefore were not chemically pure; I most readily allow that the numbers, expressing the increase of these salts in the soil in successive years, are not exact, since a certain quantity was probably carried down to such

a depth by the rain, that it was out of the reach of the plants, and therefore could produce no effect. But it is and remains undeniably certain, that the proportion of ammoniacal salts in the soil, whatever might be its exact value, must have increased from year to year, because ammoniacal salts (sulphate of ammonia and sal-ammoniac) are not volatile, and, consequently, the unconsumed portion, or excess, must have remained in the soil. This being assumed as a fact which cannot be disputed, these numbers establish the truth, already demonstrated by the earlier experiments, that the produce did not increase in proportion to the increased proportion of nitrogen present in the soil; but that, with the exception of the year 1848, the produce for the same amount of nitrogen steadily diminished. The produce, calculated with reference to 100 lbs. of ammoniacal salts, may be considered, when all sources of error are taken into account, as relatively correct. These calculated results express, not the absolute, but the relative quantities of grain and straw for an equal amount of ammoniacal salts, that is, of nitrogen. Now, since the soil, in the second year already received twice, in the third year three times, in the fourth above four times, in the fifth above six times, and in the sixth above

seven times as much nitrogen, in the form of ammoniacal salts, as the whole produce in grain and straw (the produce of the unmanured lot, *plus* the increase of produce) required of ammonia for the production of all the nitrogenised compounds contained therein, it obviously follows, *that the produce or crops were in no way proportional to the increase in the supply of nitrogen given to the soil.**

When we remember that it is the object of scientific research to discover the cause of the efficacy of ammoniacal salts, we must not forget, in our inquiries, that the increase of produce, obtained by the use of these salts, is to be regarded in itself as a firmly established fact, which can in no way be affected by the views we may entertain as to its cause.

Now, as we have already stated, when we attempt to explain the action of ammoniacal salts, two properties of these salts must be taken into consideration; one of these is the capacity of ammonia to

* Mr. P. Pusey has recently promulgated the opinion, that nitric acid, which, as I showed 26 years ago, is a constituent of rain water, especially of that of thunder storms, is a second principal source of nitrogen for plants. On the question, whether nitric acid takes a share in the process of vegetable life, I have expressed my opinions in detail in my work; and there I have said that, in any case, nitrates are manures which do not replace those mineral

serve as *food for plants*, that is, *as the source of their nitrogen;* the other is the action of sulphate of ammonia *as a solvent for certain important mineral constituents of the soil.*

If the ammonia produced this favourable effect only by its *nutritive power*, as Mr. Lawes assumes, it is quite impossible to understand why so great an excess of it was necessary in order to obtain the proportionally trifling increase of produce, compared with the unmanured land. For this unmanured land yielded, in the same period, without having received even a trace of ammoniacal salts as manure, a quantity of grain and straw exactly equal to twice the *excess* of produce obtained by the use of these salts. It seems probable, on this supposition, that a fourth, or at most a third part of the actual supply of ammoniacal salts must have sufficed to produce the increase of produce obtained.

But if, on the contrary, only a small part of the ammonia acted by its nutritive property, and by far the greater part by its solvent power for phosphates and silicates, its action is explained in a more

constituents which are removed from the soil in the crops; and even if, by virtue of their acid or their alkali, they increase the produce, the soil must, by this very increase, be rendered poorer, and be the sooner exhausted.

satisfactory manner; for in this case the effect is proportional to the quantity of water which entered the plants, and was given off by evaporation from their surface, the solvent power of this water for these substances having been increased by the ammoniacal salts. The effect of the earthy phosphates and of the soluble silicates depends on the quantity of them in the soil; their effect in a given time is proportional to the quantity which enters the plant in that time. This again is proportional to the degree of their solubility in rain water, and to the amount of rain water absorbed by the plant.

Both properties—that of ammonia as a *nutritive agent,* or source of nitrogen, and that of the ammoniacal salts as *solvents,*—have certainly co-operated to give the increased produce; for since the total produce, 28,431 lbs. of grain and straw, of the lot manured with ammoniacal salts, was to that of the unmanured land, 18,122 lbs. grain and straw, as three to two,—and consequently the excess of the former was equal to half the amount of the latter,—it is evident that this excess must have contained exactly as much silicate of potash and phosphates as existed in one-half the crop of the unmanured land. Now, since ammonia cannot replace these essential constituents of the wheat plant, it follows, that,

by the agency of the ammoniacal salts, this entire additional quantity of mineral constituents was rendered soluble and available for the plant. These salts have enabled the rain water, in equal volume, to dissolve and carry into the plant, in the same time, one-half more of these substances than was yielded, without ammoniacal salts, by the unmanured land.

I think it probable that, with reference to this last property, that is, their solvent power, the ammoniacal salts may be replaced; that chemistry will discover the means of rendering more soluble the silicates and earthy phosphates indispensable for wheat; and that thus the obstacle of high price, which so much limits the use of ammoniacal salts for this purpose, will be removed. The whole efforts of agricultural chemistry ought to be devoted to the removal of these obstacles.

According to what we have learned from the cultivation of other crops, the atmosphere is sufficiently rich in ammonia, to supply with the necessary nitrogen more than double the quantity of grain and straw which was obtained from the unmanured land. We know that a crop of turnips, grown on a soil which had received no ammonia, but only superphosphate of lime, contains twice or thrice as much

nitrogen, in its nitrogenised constituents, as a full crop of wheat in grain and straw; and that land sowed with clover, topinambour, or peas, and not receiving any nitrogenised manure whatever, condenses from the air in its products a larger amount of nitrogen than is obtained in the products of an equal surface of the same land sown with wheat, and most richly manured with ammoniacal salts.

When we shall have acquired means, such as I have alluded to, of increasing the fertility of the soil, or the efficacy of its constituents, we may be able to solve the question, whether ammonia, as a constituent of manure, may not be altogether dispensed with; or whether that quantity of it, which may be collected or saved on every farm, may not completely suffice for the objects of cultivation.

It is much to be regretted, that Mr. Lawes did not undertake a series of experiments in this direction. Had he manured the lot 10*a*, in the first year with 3 cwt. of ammoniacal salts; and had he, in the five succeeding years, added to the soil annually only 72 lbs. of these salts, to replace the amount removed in the crop, one of two cases would have occurred: either the lot would have yielded the same excess of produce as when manured with 1960 lbs. of ammoniacal salts, or the excess would

have been less considerable. In the former case we should have been enabled to conclude, with somewhat more of certainty, that the increased fertility had been caused by the ammonia *as a source of nitrogen*, by its *nutritive power;* in the latter it would have been proved, that the cause of the effect of the great excess of these salts, must be sought for in the increased solubility given by them to the mineral constituents. This, at least, is the way in which, in scientific researches, answers to distinct questions can alone be obtained.

The solution of these problems, so important and essential for practical and theoretical agriculture, is connected with the series of experiments, which I have proposed, in reference to the efficacy of the mineral constituents in their different conditions of solubility. The two series of experiments might be combined; and we might make a trial, using, in one case, mineral manure alone; in another, mineral manure to which a sufficient quantity of ammoniacal salts dissolved in water has been added—about as much ammoniacal salts as will supply, with the necessary nitrogen, from one-third to one-half of a crop of grain and straw. The results would be decisive as to the advantage to be derived from the use of these salts as manure for certain plants.

From a comparison of the produce of the unmanured lot No. 3, with the *excess of produce* in the lot 10*a*, manured with ammoniacal salts, it appears that the effect of the constituents of the soil by themselves (without ammoniacal manure) was double the effect of 1960 lbs., that is, of a most enormous excess of ammoniacal salts. These numbers, perhaps, express more distinctly what I took so much pains to show in my work, that in practical farming the attainment of heavier crops, and of a higher rent, depends much more on the removal of obstacles, the giving to the soil a proper physical quality, and the solubility or available state of the necessary mineral constituents, than on ammonia; and that on poor soils, it is far more important to attend to the due restoration, and the increase if possible, of these indispensable mineral substances, than to the supply of ammoniacal salts *alone*. In this point of view, every one knows what has been the effect of the drainage system. In many cases it has raised the produce by one-half, or even doubled it.

To seek to ascertain the effect of ammoniacal salts in the way Mr. Lawes has done, and to recommend the use of these salts for the cultivation of wheat, seems to me almost a mockery in the present state of agriculture; for all the ammoniacal salts

manufactured in Europe are not sufficient to supply the lands of even the kingdom of Saxony with these salts, in the quantities recommended by Mr. Lawes. It has been known for centuries, that nitrogenised manures are useful for certain crops; that the active mineral substances become more efficacious by the addition of ammoniacal salts than without them, is a conclusion, as is proved by the quotations from my work, simply deduced from theory, to test which no experiments are necessary. But so to prepare the soil as to enable it to extract from the air, and the other sources offered to plants by nature, and to condense in its products *a maximum of nitrogen*,—this, indeed, is a problem worthy of scientific agriculture.

The results of Mr. Lawes have no value for his next-door neighbour, nay, they have no value for himself; for the recipe, to which he comes, only applies to his own lands, and to them only, in so far as experimented on, and only for a very limited number of years. No new principle, correcting an existing one, and no new mode of culture, has been derived from his experiments; and if he has called in the aid of Dr. Gilbert, with reference to chemical analysis, this sort of agricultural chemistry is nothing more than dressing up a corpse with useless

and unnecessary ornament. It will, I suppose, be admitted, that I know the value of an analysis; but in my opinion, a long time must elapse before we can apply an analysis to the solution of agricultural problems, excepting of course the analyses of manures and soils. The agricultural chemist should be occupied with questions infinitely more important than these; but it is no doubt much more difficult to find a man who possesses the power of thought and reflection, than one who is expert in analysis.

Ammonia, when used as a manure alone, and when there is a want of mineral constituents in the soil, is like the spirits which the labourer takes, in order to increase his available labour, power, or imagination; and, like that stimulant, its action, in this case, is followed by a corresponding exhaustion. It is in vain for the farmer to hope for some undiscovered source of ammonia, for even if such a source were discovered, and yielded a profuse supply, yet the agriculturist who wishes to leave to his children fertile lands, *must always find himself driven back to the immutable natural law, that the quantity of mineral constituents removed in the crops, must be restored to the soil.* No discovery, no progress, will ever be able to circumscribe the range of this law, or to relieve us from its operation.

In order not to excite new doubts, and in order to put an end to a misunderstanding, which I thought, but vainly, as it appears, I had rendered impossible in my work, I repeat here what I said in that work (p. 212) :—"In order to obviate any misunderstanding, we must again draw attention to the fact that this explanation is not in any way contradicted by the effects produced on the application of artificial ammonia, or of its salts. Ammonia is, and will continue to be, the source of all the nitrogen of plants; its supply is never injurious; on the contrary, it is always useful, and, for certain purposes, indispensable." I repeat, therefore, once more, that I regard ammonia and ammoniacal salts as exceedingly useful, nay, in the present day, quite indispensable, if we would increase the produce of our land beyond a certain limit without the use of farm-yard manure. This is a certain and acknowledged fact, which every farmer knows how to apply with profit, by proper arrangements for collecting the manure, both solid and liquid, produced on his farm. That which I wish to point out, and to which I desire to direct the experiments of scientific agriculturists, is the notion, confirmed by the analysis I have given of Mr. Lawes's experiments, that, by certain improvements in the

management of the land and of the manures, ammonia, not as a source of nitrogen, but as a promoter of the solubility, and consequently of the action, of certain mineral constituents of the soil, may be dispensed with, or that we shall at least ultimately be enabled to dispense with it. I consider it an error to estimate the value of a manure by its per centage of nitrogen; and hence ammonia and ammoniacal salts cannot be placed on the same level as poudrette and guano, because the latter contain, along with ammonia, a quantity of nutritive mineral substances which are quite as important, nay far more important to the plants than ammonia by itself can be. In every manure, the ashes, or mineral constituents must be carefully taken into account in estimating its value.

Now, when we reflect that the lot No. 3, unmanured, yielded in seven years a produce of 20,165 lbs. of grain and straw; that the manured lot 10, yielded in the same time 30,559 lbs. of grain and straw; that the produce of the unmanured lot was the sum of the action of all the constituents of the soil, without any artificial supply of ammonia; that the produce of the manured lot was the sum of the action of the same constituents of the soil, *plus 560 lbs. of superphosphate of lime, plus* 220 *lbs.*

soluble silicate of potash, plus 1960 *lbs. of ammoniacal salts*;—it follows that the increase of produce was by no means the effect of the ammonia *alone*, as Mr. Lawes will have it, but that the active mineral constituents of the soil, just mentioned, have had their full share in producing this effect.

What, then, are the circumstances in which theory leads us to anticipate such an increase of produce?

The answer will be found in my work, p. 134:—

"The cereals require the *alkalies* and *silicates*, liberated by the lime and rendered fit for assimilation by plants. If there be present decaying matter yielding to the plants carbonic acid, their development may be favoured by this means, but this is not necessary. For if we furnish to the soil *ammonia*, and to the cereals the *phosphates essential to their growth*, we furnish all the conditions necessary for a rich crop."

Now, what are the circumstances under which Mr. Lawes obtained his increased produce? He supplied his soil with *soluble silicate of potash*, with *phosphate of lime*, and with *ammonia*; and, therefore, after seven years of experiments, he obtained results which are in the most complete agreement with my theory,—facts which are absolutely irre-

futable proofs of its truth. It is impossible to believe that Mr. Lawes was at all acquainted with that theory, or that he knew what my doctrine was; for otherwise how is it conceivable that he should have regarded his results as incompatible with that doctrine; or how could he possibly have said, that it follows from his experiments on the whole, "*that nitrogenised manures are peculiarly adapted to the growth of the wheat plant?*" Or how otherwise could he have said, in 1847 (vol. viii. p. 245), "The theory advanced by Liebig, that 'the crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substances conveyed to it in manure,' is calculated so seriously to mislead the agriculturist, that it is highly important its fallacies should be generally known. *The contempt which the practical farmer feels for the science of agricultural chemistry arises from the errors which have been committed by its professors.*"

Had Mr. Pusey known the theory as it really is, would he have had the boldness to say (Journal, vol. xi. p. 383) that "The axiom of Liebig, 'the crops in a field diminish or increase in exact proportion to the diminution or increase of the mineral substances conveyed to them in manure,' has

received a death-blow from Mr. Lawes's experiments." Again (p. 392), "The Mineral Theory hastily adopted by Liebig has broken down; no other has taken its place. Our best authority, Mr. Lawes, has certainly proved so much, that of the two active principles in manure, ammonia is specially suited to corn, phosphorus to turnips, and that turnips are *probably* benefited by the woody matter of straw."

None of all these facts are new, and what is new in the opinion of Mr. Lawes is erroneous. Long before Mr. Lawes made his experiments the action of ammonia on wheat and that of phosphate of lime dissolved in acid on turnips, were well known.

Truly agriculture need not be envied this triumph gained by means of the agriculturo-chemical experiments (as he himself calls them) of Mr. Lawes, if the only theory she had has thus fallen to pieces, and its place has been supplied by no other. What a gain it is to know, that of all active matters, ammonia is especially suited to grain and phosphorus to turnips!

Agricultural chemistry does not assist agriculture merely to produce grain and meat, for this has been done for many centuries; but her aid is given to enable agriculture to produce *more* grain, *more* meat,

or grain and meat by the *simplest* means, and in *the most profitable way.* The chemist searches for the method and the means; but this is all he can do, and the agriculturist must undertake the rest. But what has agriculture done to support agricultural chemistry in this direction?

The former president of the Royal Agricultural Society of England, Mr. Pusey, gives to this question, in the year 1850, the following answer: "Except Liebig's suggestion for dissolving bones with acid, and Sir Robert Kane's for using flax water as manure, I know no agricultural process arising out of chemical discovery." This statement explains everything. It is not the doctrine which is wanted, but *recipes*;—thought and reflection are left to the chemists. Many agriculturists are like children, who, groping in the dark, stumble over the sign-post put up to show the way, and who now beat the sign-post which has caused them to fall. But sign-posts are not intended for the use of the blind. The chemist is only such a sign-post, which cannot move from its place. The path that leads to truth is a straight one, intersected by millions of curved ones; it is in vain to hope that we can find the right path by groping in the dark.

Medicine, Physiology, and Mineralogy, a few

centuries ago, stood to Chemistry in a similar relation to that which now exists between Agriculture and Chemistry. Since physicians, physiologists, and mineralogists began to acquire that amount of chemical knowledge which enabled them *to obtain for themselves answers to their questions*, these sciences have made such progress as was never before known. The living organism, the pathological phenomenon, and the mineral, are, like everything which is external to the laboratory of the chemist, not more accessible to his researches than the farmer's fields.

I am convinced that farmers will find, in books which treat of the application of chemistry to agriculture, dozens of prescriptions or recipes like that alluded to by Mr. Pusey. The difficulty is to discover them, and to give them vitality. Mere proposals can never make land fertile. Such recipes may have a high value in agriculture, at least in special cases, but in a chemical point of view, they have no greater scientific value than a recipe for good blacking, because they are simple deductions from certain principles. It is not the deductions, but the principles alone, which constitute the problem to be solved by the chemist.

But to render even a deduction effectual by means

of experiment, requires a certain force of conviction, or faith, which few possess; for without this force, we cannot overcome difficulties. The certainty that, with the right means, we *must* obtain the desired end, determines our success; for by this certainty we are led to find the right means. But, unfortunately, up to this time, doubt, not conviction, has prevailed in agriculture. We cannot find two farmers who are of one mind concerning one and the same phenomenon; for example, the effect of nitrate of soda, or that of drainage.

I cannot conclude these long explanations without once more returning to Mr. Lawes. I wish to do him full justice.

At the end of his memoir (Journal, xii. p. 39), he says:—"In conclusion, then; if the theory of Baron Liebig simply implies that the growing plant must have within its reach a sufficiency of the mineral constituents of which it is to be built up, we fully and entirely assent to *so evident a truism; but if, on the other hand, he would have it understood that it is in the mineral constituents, as would be collectively found in the ashes of the exported produce that our soils are deficient relatively to other constituents, and that, in the present condition of agriculture in Great Britain, 'we cannot increase the fertility of our fields by a*

supply of nitrogenised products, or by salts of ammonia alone, but rather that their produce increases or diminishes, in a direct ratio, with the supply of mineral elements capable of assimilation,' we do not hesitate to say that every fact with which we are acquainted, in ratio to this point, is unfavourable to such a view."

In the first part of this quotation, Mr. Lawes admits the truth of the so-called Mineral Theory; in the second I find two erroneous statements, the continued diffusion of which I can no longer tolerate.

The concluding sentence ascribes to me the assertion that the produce of land is proportional to the supply or diminution of the available mineral constituents. This I have never said: I have stated, that the produce is proportional to the available mineral constituents *in the manure*, by which phrase, of course, I meant to refer to manure generally, including *mineral manure, guano, poudrette, farm-yard manure*, &c.

With regard to the previous sentence, I find in my work only one passage in which I speak of the land of England in the sense understood by Mr. Lawes. This is page 165: "In the large towns of England, the products of English as well as of foreign agriculture are consumed; and to

supply this great consumption the constituents of the soil necessary to the plants are removed with them from an immense surface of land, to which they are not again returned. The domestic arrangements peculiar to the English render it difficult, perhaps even impossible, to collect the immense quantity of phosphates (the most important ingredients of the soil, although present in it in a small quantity) which are daily sent into the rivers in the form of urine and of solid excrements. Thousands of hundredweights of phosphates flow annually into the sea with the Thames, and with other of the British rivers. Thousands of hundredweights of the same materials, arising from the sea, annually flow back again into that land in the form of guano."

It is not difficult to refute the opinions of another, if we ascribe to him assertions which he has never made.

It never occurred to me to assert that the land of Great Britain was deficient in the substances which are found together in the ashes of the crops raised on it, or that, on a soil naturally fertile, rich crops might not be obtained for several successive years, *by the use of ammoniacal salts alone.* The state of the land in England generally, and of that of

Mr. Lawes in particular, is quite unknown to me; but I have no doubt whatever, that, by a well-devised analysis of his soil, we should be enabled to predict all the results, to arrive at which he took seven years' experiments. I have asserted, and my assertion is only confirmed by the experiments of Mr. Lawes, that *ammoniacal salts alone*, if used uninterruptedly, must, sooner or later, *exhaust the soil.*

Agriculturists have derived sufficient profit from the use of guano, and from the knowledge of the true cause of the efficacy of bones as manure, which I mentioned in the passage quoted from my work, but they are too ready to forget the actual state of agriculture up to the year 1840.

When, in September, 1840, the first edition of my work appeared, not a single pound of guano had been used by farmers as manure; and if any one will take the trouble to compare the produce of English agriculture, since 1841, in corn and cattle, with the produce of the same land before 1840, he will find, that by the use of guano, against which so many voices were at first raised, till the right mode of using it was learned, the produce of the land has risen to an extent which has hardly been equalled by the results of any other discovery in agriculture.

I do not say this to claim any merit for myself, because Humboldt and Boussingault had long before pointed out the value of guano to those countries in which it had been used from time immemorial. But guano was known to me only by its constituents; and it is surely no small proof of the truth of a theory, that, on the strength of an analysis alone, it has not been deceived in the judgment it formed of the importance of such a manure.

Previous to 1840, the prevalent ideas concerning the fertilisation and enrichment of the land, revolved about the obscure and dim notions of humus and manure, as then understood. How different are now the views entertained on these points!

The more we enter into the spirit of the writings of Mr. Lawes, the more we are astounded at the fundamental error to which, as to a black thread, all his experiments and all his ideas attach themselves. On almost every page he assures us with the utmost confidence, that my theory must be erroneous, and that I have only to follow with attention his experiments, in order to convince myself how little applicable they are to practical farming, because I have advised the farmer to take measures to ensure the full restoration to the soil of the alkalies, the alkaline earths, and the phosphates,

in proportion as they are removed from the soil. Whereas,—and this is the chief argument of Mr. Lawes against the doctrine,—his land, and that of England generally, exporting corn and cattle, are deficient only in *phosphoric acid* and *nitrogen*, which substances are replaced by imported cattle, bone-earth, and guano; while all the other mineral constituents of the soil are restored to the land, according to the usual methods of English farming, by means of the farm-yard manure, and that almost without loss.

But if this be really the case, then the farmer acts entirely according to the principles of my theory, which tells him, that in such cases an additional replacement, by means of mineral manure, is not at all indicated. The form in which that which has been removed from the soil is restored to it, is of no importance whatever, provided it be an available one. At p. 186 of my work, I said on this point: "It must be admitted as a principle of agriculture, that those substances which have been removed from a soil must be completely restored to it; but whether this restoration be effected by means of excrements, ashes, or bones, is in a great measure a matter of indifference." Again, p. 177: "It is evident that all the constituents of the field removed from it in the form of animals, corn, and fruit, may

again be obtained in the liquid and solid excrements of man, and in the bones and blood of the slaughtered animals. It altogether depends upon us to keep our fields in a constant state of composition and fertility, by the careful collection of these substances." Again, p. 178: "The principal object of agriculture is to restore to our land the substances removed from it, and which the atmosphere cannot yield, in whatever way the restoration can be most conveniently effected."

It is altogether incomprehensible, that it should never for one moment have occurred to Mr. Lawes, that in Germany, France, and even England, all land has not the quality of his land; that the universal and best founded complaint of most farmers refers to the difficulty of restoring and exalting the fertility of their land, in consequence of the want of farm-yard or stable manure; that, in a number of cases, from want of cattle or of meadow-land, or because none of the land is adapted for the raising of green crops or fodder, a complete restoration of what is taken from the soil, at least in the form of stable or farm-yard manure, is utterly impossible. What then are farmers, thus situated, to do, in order to increase their produce and improve their soil? I should have regarded it as a very

great gain, and I should have gladly renounced all endeavours to expose the errors of Mr. Lawes in regard to my views, if his experiments had contributed ever so little to the solution of this question. But how can Mr. Lawes, like a wealthy man, who has a secure income, blame science for opening up to the needy sources of help, which he, Mr. Lawes, does not need and considers insignificant? Ought not the light of science to shine both on rich and on poor soils alike?

There are whole countries, as in the Netherlands, Flanders, and Westphalia, where the use of ashes as manure has long yielded the best returns; and where, according to Schwerz, the proverb is current, that *he who expends nothing on ashes, is sure in the end to pay double* ("Introduction to Pract. Agric.," vol. ii. p. 323).

The opinions of Mr. Lawes have found an echo in Germany. In the latest work of Wolff, "The Fundamental Natural Laws of Agriculture," vol ii. p. 424, he says:

"If we compare the facts above mentioned, derived immediately from experience and from numerous field experiments, with the chemical composition of the crops, and with the qualities of the essential constituents of manure which are contained

in the produce of a given surface, we acquire the conviction, that the exhaustion caused by the cultivation of different crops is in no way directly proportional to the quantity and quality of the organic and mineral constituents present in the crops; and further, that the pure Mineral Theory, founded and formerly defended by Liebig, has not been confirmed by the practical experience of agriculturists."

Such conclusions, on the part of a writer on agriculture, would almost lead one to doubt of the possibility of progress. "*The exhaustion of the soil is declared to stand in no way in direct relation to the produce obtained from it. That is, the effect (exhaustion) bears no relation to the (exhausting) cause!!*"

In the experiments of Mr. Lawes we recognise the facts and observations on which such opinions and such *dicta* are founded.

No housewife ever imagines that she can judge of the price of a piece of cloth, or its equivalent in money, without knowing its length and breadth, that is, without a yard measure. But the writers on agriculture, with reference to agricultural facts, and so-called observations, are much better off. Without using the measure of scientific principles,

indeed without any measure whatever, they mete out to us the value, the depth, the breadth, in short, the whole extent and significance of their experience. Nay, many of them express a kind of satisfaction on finding that the measure offered to them by science, is still, in the present state of agriculture, so imperfect and so little applicable. And these are just the men, whose vocation it should be to assist in improving it, and, if it be applicable, to teach the right method of using it. Herr Wolff also believes and teaches, that the "pure (?) Mineral Theory, founded and formerly defended by Liebig, has not been confirmed ;" and he rests his conclusion on the dunghill—as we may call it, in the best sense of the word—of the *practical experiences* of farmers. These are, in fact, only the manure for a future rational system of culture. That the Mineral Theory of Liebig is a *pure* fancy of Mr. Lawes, is probably by this time clear to the reader; but I am entirely at a loss to discover, in which of my writings Herr Wolff has found what he calls the pure Mineral Theory.

It seems to me worth while to consider here one more of those unmeaning practical experiences, made by one who is, according to Mr. Pusey, the first agricultural authority in England, namely, by Mr. Lawes.

It refers to the growth of turnips. (Vol. xii. p. 34, and vol. viii. Part 2, p. 26, *et seq.*)

An average crop of turnips (8½ tons per acre), according to the best analysis, requires for its development, from the soil, 50 lbs. of phosphate of lime, a quantity relatively very small, and 127 lbs. of potash; therefore, about 2½ times as much potash as phosphate. But Mr. Lawes tells us, that neither potash, nor any other constituent of the ash of turnips, nor yet ammoniacal salts, had, on his land, a favourable effect on the turnip crop; phosphoric acid alone was found efficacious; and this he proves in the following manner. An experimental lot was, during the years 1843 to 1850, manured annually with nothing else than a mixture of phosphate of lime (burnt bones) and sulphuric acid. The field, or lot, received annually 400 lbs. of bones and sulphuric acid; and in the first year it yielded 12 tons, in the last, 11 tons 9 cwt., on the average 8¼ tons of turnips. "It is quite certain," says Mr. Lawes, "that the phosphoric acid, given in the manure, although constituting so small a part of the ash of turnips, exerts a very striking influence on the growth of the turnips." And, indeed, the experiment is a very remarkable one, and clearly demonstrates the existence of a very unusual quality of

the soil. But if we inquire into the reason why the credit of this striking result is given to the phosphoric acid, we find that this is a sheer fancy. Were any one to assert that, under the circumstances, it was the free sulphuric acid which produced the result, it would be difficult to disprove the assertion, as will be seen from the following calculations :—

Of the 400 lbs. of phosphate of lime, and sulphuric acid, supplied to the land in the first year, there remained, after harvest, as the crop removed only 50 lbs. of the former, beyond all doubt, 350 lbs. of phosphate of lime in the soil. After the second crop, the soil contained twice as much; or 700 lbs. of phosphate, and 400 lbs. more of this salt with sulphuric acid were still required in addition, in order to obtain a third crop. How strange is this! The soil, in the fourth year, already contained (after deducting the phosphate of lime of the three preceding crops), 1050 lbs. of phosphate of lime, that is, 650 lbs. more than were given to it in the first year; and yet it was necessary to add again 400 lbs. of burnt bones and sulphuric acid in order to supply the phosphoric acid (?) necessary for a fourth crop. In like manner, in the seventh year, after the sixth crop, the soil contained 2450 lbs. of phosphate of lime, or 2050 lbs. more than was

added to it in the first year, and still it required, anew, 400 lbs. of burnt bones, and sulphuric acid, in order to yield the seventh crop!! That is, to a soil, which at the beginning of the seventh year was so rich in phosphoric acid, that it contained enough for *fifty average crops* of turnips, it was necessary to add, in order to obtain the seventh crop, once more, about eight times as much phosphoric acid, as that crop really required. It is impossible to believe that the effect, in the seventh year, under these circumstances, can have depended on the newly added phosphoric acid, as Mr. Lawes concludes. If we continue our examination, we shall find, still in his own experiments, much more convincing proofs that the excess of phosphoric acid cannot have been the cause of the increased produce.*

* In comparing these numbers with the number of pounds of phosphate of lime, which Mr. Lawes annually gave to the lot No. 22, excluding all other manures, the reader will observe a discrepancy. I have assumed that he applied annually 400 lbs. of phosphate of lime; but the actual quantity was far greater. Mr. Lawes manured his lot—

In 1843, with 504 lbs. (4½ cwt.) of sulphuric acid and phosphate of lime.
In 1844, with 560 lbs. (5 cwt.) of superphosphate of lime.
In 1845, with 1232 lbs. (11 cwt.) of superphosphate of lime.

Or, in these 3 years, with 2296 lbs. of superphosphate of lime. Of the amount given from 1846 to 1850, I find no record in his

In 1843, the average crop, after the use of 400 lbs. of burnt bones, and sulphuric acid, was 11 tons of turnips.

But, strange to say, in that same year, an equal surface of land, manured only with clay and ashes (the ashes of weeds), also yielded 11 tons of turnips.

In the same year, another equal portion of land (No. 1), manured with 12 tons of stable manure, yielded 9 tons 9 cwt. of turnips, or two tons less than was obtained from the land manured with 400 lbs. of bones and sulphuric acid.

In 1844, the lot last mentioned yielded, when manured with 12 tons of stable manure, 10 tons 15 cwt. of turnips, or 2 tons 5 cwt. more than the average produce (8½ tons) of the land manured with bones and sulphuric acid.

In 1845, another lot of equal size, manured with 12 cwt. of gypsum (the residue of the manufacture of tartaric acid), and 10 cwt. of rape cake, yielded 18 tons 1 cwt. of turnips, that is, 6 tons more than

memoir; he says only, that he gave annually a strong manuring of superphosphate of lime. Since the sulphuric acid required to dissolve bones amounts to from 20 to 30 per cent. of their weight, I have assumed for every year, as a minimum, the quantity of phosphate of lime which he gave in the first year. The lot No. 21, received, in 1843, 7 bushels of unburnt bones, dissolved in sulphuric acid; in 1844, 374 lbs. of apatite (native phosphate of lime) and 104 lbs. of sulphuric acid; and, in 1845, 400 lbs. of burnt bones and 400 lbs. of sulphuric acid.

the highest produce (12 tons) of the land manured with bones and sulphuric acid, and nearly 10 tons more than its average produce, or more than double of this last, which was 8½ tons.

In the same year the lot No. 1, manured with 12 tons of stable manure, yielded 17 tons of turnips, that is, 5 tons more than was that year obtained on the land manured with bones and sulphuric acid, and double of the average produce of the latter.

What strange results are presented to us by these facts, which are no doubt accurately reported, and in what incomprehensible contradiction do they stand to the opinions of Mr. Lawes! The lots manured with stable manure yielded, on an average, heavier crops than those which received an enormous quantity of phosphoric acid; and yet stable manure contains in 12 tons, of which 8·7 tons are water, and only 3·3 tons solid matter, not more than from 46 lbs. to 56 lbs. of phosphate of lime,—a quantity barely sufficient for a full crop of turnips, without any excess whatever of phosphoric acid!

Still more incomprehensible, on Mr. Lawes's doctrine, is the fact that the lot manured with clay and ashes gave an equally heavy crop, and that the produce of the lot manured with gypsum and rape cake exceeded that of all the other lots. For this

last manure contains, in the rape cake, only 26 lbs. of phosphoric acid, equivalent to about 56 lbs. of phosphate of lime, about the quantity required for an average crop of turnips!

And now, among the substances added to the soil, which is it that has had so marked an influence on the growth of the turnips? It is out of the question, after the facts just related, to assume that the excess of phosphoric acid was necessary, and was the cause of the increase. Is it then the sulphuric acid, the lime, or both together (gypsum), or is it the organic matter in the stable manure and in the rape cake?

What conclusion would Mr. Lawes have come to, had he manured his land, for two years, only with phosphate of lime, and had added, in the six succeeding years, 400 lbs. of sulphuric acid alone, and had he thus obtained the same produce, in eight years, as if he had used 3200 lbs. of burnt bones?

Must it not be obvious to every farmer, that conclusions, based on experiments so rough, and instituted with such an utter want of caution, are entirely worthless?

Because *it occurred to Mr. Lawes* to give to his land so great an excess of phosphoric acid, are we

therefore compelled to ascribe the effect to that excess? Have we made, after all, but a hair-breadth's progress from our old position? And then, how logically does Mr. Lawes use the experiments I have here examined, to convict me of an error, and to overturn utterly the so-called Mineral Theory?

In the English edition of my "Chemical Letters," p. 522, I had said: "An enormous quantity of these substances, indispensable to the nourishment of plants, is annually withdrawn from the soil, and carried into great towns, in the shape of flour, cattle, &c. It is certain that this incessant removal of the phosphates must tend to exhaust the land and diminish its capability of producing grain. The fields of Great Britain are in a state of progressive exhaustion from this cause, as is proved by the rapid extension of the cultivation of turnips and mangel-wurzel—plants which contain the least amount of the phosphates, and therefore require the smallest quantity for their development."

No one, however strongly prepossessed, can perceive in these sentences a recipe for manuring turnips; for the word manure does not once occur.

But Mr. Lawes answers (Journal, xii. p. 33):

"Professor Liebig has again, in the recent edi-

tion of his "Letters," expressed an opinion entirely inconsistent with such a result. We do not hesitate to say, that, however small the quantity of phosphates contained in the turnips, the successful cultivation of it is more dependant upon a large supply of phosphoric acid in the manure than that of any other crop."

No one surely can believe that my statement as to the very small proportion of phosphates in turnips is untrue, *because* Mr. Lawes has misunderstood the meaning of the sentences above quoted from my work. My remarks had no reference whatever to the manuring of turnips, but were designed to direct attention to the difference between turnips and other crops which require in certain periods of their growth more phosphates than turnips do. With reference to the cultivation of grain, I wished to show that the growth of turnips had acquired so vast an extension, *for this reason*, namely, *because the soil loses so little of the phosphates by the cultivation of the latter crop.* Turnips are so advantageous in a rotation, only because, whatever be the quantity of phosphates contained in the soil, or added to it in the manure, they leave in the soil so large an amount of these indispensable salts for other crops,

which require a larger supply of them. Mr. Lawes himself states (Journal, viii. p. 70), that an average crop of turnips only extracts from the soil 50 lbs. of phosphate of lime, even when the soil contains fifty times that quantity. Would the extension of turnip husbandry, then, be advantageous, or even possible, if a crop of turnips removed from the soil, instead of 50 lbs. of phosphate, 200 lbs. or more? The small per centage of phosphates in turnips is the reason why, in Germany and France, there is often obtained, after grain, a stubble crop of turnips in the same year.*

If the reader will peruse the Letter in question,

* If we calculate from the results of ash-analyses the quantities of phosphoric acid which are required respectively by a wheat-crop, including grain and straw, and by a turnip-crop, including roots and leaves, we find that wheat removes less of this substance from the soil than turnips. This result is apparently in contradiction to the fact so well established by practical experience, that wheat requires more abundant supplies of phosphoric acid in the soil than the turnip. The two facts become reconciled when we take into account the longer time which the latter has in which to accumulate this mineral ingredient.

The turnip requires phosphoric acid to be supplied through the whole of its long period of growth, four or five months, but uniformly, and always in small quantity only, in any given time. Wheat needs the greater share of its phosphoric acid during the growth of the seed. This is the period in which, as practical men believe, the soil suffers the greatest loss,—is most exhausted. If the wheat-plant find a sufficient quantity of phosphoric acid within reach of its roots during the few weeks in which its seed is formed, then each kernel attains a full and normal development: if there be a slight deficiency of phosphoric acid, then the seeds are less nu-

(Letter xxxv. of the English edition), in which occurs the remark which Mr. Lawes has interpreted unfavourably for my views; he will perceive that the use made of that remark by Mr. Lawes does not do me justice. During my travels in England in 1842, I had become acquainted with the great deposits of coprolites in that country; and by analyses I had detected in these remains of an earlier period, a large quantity of phosphate of lime. This was, for British agriculture, a great and hitherto undiscovered treasure,—a mine, as it were, of a substance for which, in the shape of imported bones, Great Britain was necessarily tributary to foreign countries. The thirty-fifth

merous or less large: if the deficiency be very considerable then nothing but straw is produced.

The quantity of phosphoric acid, which a wheat-soil should contain, does not therefore stand in relation to the sum total which the plant needs, but to the quantity which the kernels require during the period of their development.

When we compare the quantity of phosphoric acid which the soil must yield to a wheat-crop during the month in which its seeds are forming, with that needed by a turnip-crop in any equal space of time, it is plain that wheat requires the presence of a far larger amount of this indispensable body in the soil than the turnip. This is a fact not to be disregarded in manuring the soil for these crops.

The produce of a field stands related to the amount of that mineral ingredient which its soil contains in smallest quantity.

As a general rule, the manuring of a field should not be calculated from the sum total of mineral ingredients which the plant takes from the soil, but must be proportioned to that maximum of these substances which is required by the plant in a certain period of its growth.

Letter of the English edition had no other object than to direct the attention of British farmers to this treasure (that Letter does not occur in the German edition). My advice has borne good fruit. A manufacturer of coprolite manure in the neighbourhood of Oxford, who quarries the coprolites and brings them into the market dissolved by sulphuric acid, assured me, when I met him at my friend Dr. Daubeny's in Oxford, in 1851, that he alone had already supplied the market with this manure to the value of £50,000; but also that a much larger quantity was prepared by farmers on their farms, and used by them on their own land.

To conclude:

1. Mr. Lawes has *proved* that his land contained an excess of those mineral constituents which are required for their perfect development, by seven crops of wheat, in grain and straw, during seven years.

2. Mr. Lawes has *proved* what is predicted alike by theory and by sound common sense, that the produce of such land cannot be increased; or can at most only be increased in proportion to the whole sum of such constituents present in the soil, by manuring with these same mineral constituents.*

* By manuring with 3 cart loads of the ashes of wheat-straw, the produce rose from 71¾ pecks per acre, to 76½ pecks, that is, by

3. Mr. Lawes has *proved*, what theory teaches us, that the produce of such land may be increased by manuring with ammoniacal salts.

4. Mr. Lawes has *disproved* what he intended to *prove*, namely, that the excess of produce in this case is proportional to the quantity of ammonia present in the soil;—that is, he has proved that a single, double, or treble supply of ammonia does not give a single, double, or treble excess of produce; but that this excess is a constant quantity.

5. Mr. Lawes has *proved* what he intended to *disprove*, namely, that the whole produce is proportional to the one only constant value which operated in his experiments, that is, to the total sum of the available or soluble nutritive mineral constituents present in the soil. He has *proved* what theory teaches, that the use of ammonia increases the action of the mineral constituents *in a given time;* that is, that in the same time a greater amount of mineral constituents become thereby active or available.*

about $\frac{1}{13}$th of the whole. By manuring with 418 lbs. of Liebig's mineral manure, for wheat, the produce rose from 71$\frac{3}{4}$ pecks per acre, to 81$\frac{1}{8}$ pecks, that is, by rather more than $\frac{1}{7}$th of the whole.

* We can exalt the mechanical effect of substance by altering or improving its mechanical condition; we can, for example, render a blunt knife sharp; or we can make from the same bar of steel two razors, one of which is so much better than the other, that it will remove twice as many beards as the other before it becomes

On an early occasion I shall consider more particularly the experiments of Mr. Lawes on the fattening of sheep, and on the cultivation of turnips.

blunt. But we can in no way exalt the chemical effect of a substance, so as, for example, to make 1 lb. of carbonic acid, or ammonia, produce the same effect as 2 lbs. of carbonic acid, or ammonia; because, other things being the same, the chemical effect is proportional to the masses, that is, to the sum of active material parts, which are the carriers, as it were, of the force exerted. The effect *in a given time* is greater when, in that time, more material particles come into action. 1 lb. of sugar in fine powder dissolves in water much sooner than 1 lb. of sugar in large lumps, not because the attractive force is greater, by which the solution is effected, but because, on account of the increased (acting) surface given to the sugar, a greater (acting) surface of water comes in contact with it in the same time.

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